ILLDOE-81/34

ILLINOIS ENERGY PLAN

Staff Working Paper

ILLINOIS RENEWABLE RESOURCE SUMMARY AND TECHNOLOGY ASSESSMENT

For Public Comment

Illinois Institute of Natural Resources

ILLINOIS ENERGY PLAN

ILLINOIS RENEWABLE RESOURCE SUMMARY AND TECHNOLOGY ASSESSMENT

State of Illinois
Institute of Natural Resources
325 West Adams
Springfield, Illinois

To obtain further information or additional copies of this publication, call or write to:

Energy Plan
Institute of Natural Resources
325 West Adams, Room 300
Springfield, IL 62706
Phone: 217/785-3416

Or mail the form below to the above address:

Please send me _____ copies of Illinois Renewable Resource Summary and Technology Assessment.

Name ______________________________

Address ______________________________

City ______________________________

State ________________ Zip __________

ACKNOWLEDGMENT

The Illinois Renewable Resource Summary and Technology Assessment publication of the Illinois Energy Plan has been prepared by the Solar and BioFuels Sections of the Institute's Resource Development Division. Special thanks are in order to the following people who assisted in the development of this document: Mitch Beaver, Tom Heavisides, K. Hemadri, Liz Johnson, Bob Lindquist, Dave Loos, Terry Miller, Kathy Coleman and Tim Warren.

In addition, we would like to express our appreciation to our clerical support staff, especially Angie Tait, and the Word Processing staff: Sherry Irving, Karen Goddard, Dolores Proctor and Judy Yee. Many thanks to Joan Ryan and Bob Shirley for their work in producing this report.

TABLE OF CONTENTS

ILLINOIS

SOLAR AND WIND RESOURCE SUMMARY

AND TECHNOLOGY ASSESSMENT

INTRODUCTION

The total percentage of Illinois' energy demand which can be met by solar energy and wind energy technologies depends on the total solar radiation (sunlight) falling on Illinois, the total wind resource, as well as the availability and efficiency of technologies with which to capture it. This overview will discuss the availability of sun and wind in Illinois. It will also briefly describe the various solar and wind technologies and their potential applicablility in Illinois.

SOLAR AND WIND ENERGY USE IN ILLINOIS --

AN OVERVIEW OF THE AVAILABLE RESOURCES AND TECHNOLOGIES

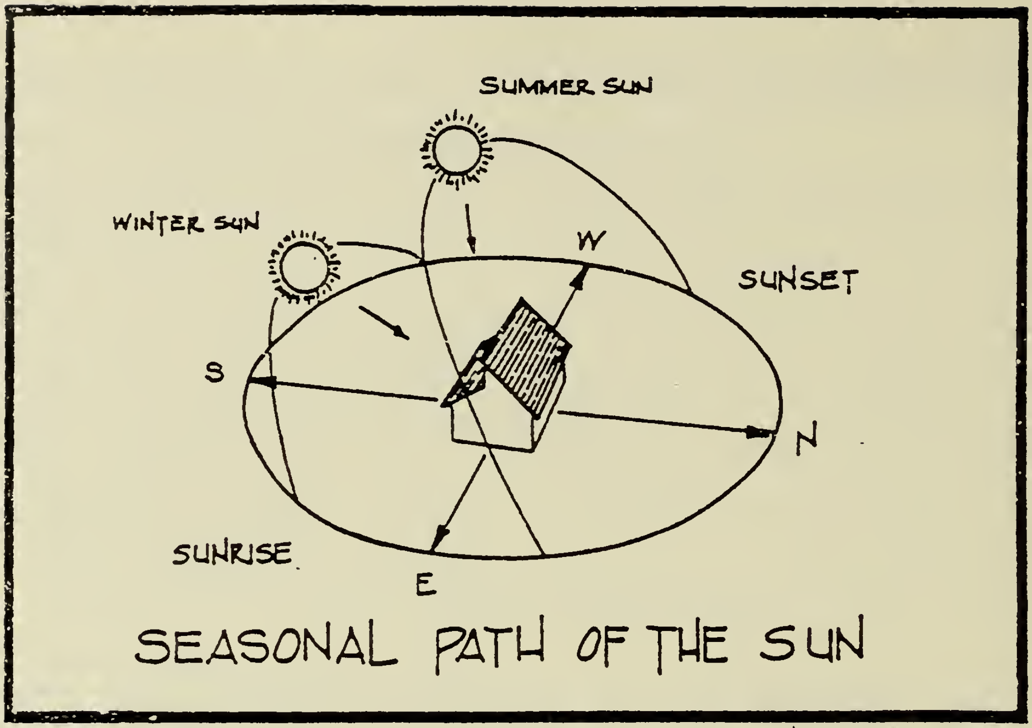
Table of Contents

AVAILABLE SOLAR ENERGY IN ILLINOIS

In general, three factors affect the amount of solar energy available on earth. They are 1) the number of hours of daylight, 2) the angle at which the sun's rays strike the earth, and 3) the amount of sunlight reaching earth through the atmosphere. Solar energy availability varies seasonally and daily because of the rotation of the earth and the tilt of the earth's axis. Further, it varies because of atmospheric conditions such as cloudiness and the level of pollutants in the atmosphere.

Obviously, the rotation of the earth causes day and night and makes it impossible to collect solar energy 24 hours per day. However, the length of day and night varies from season to season because of the tilt of the earth's axis. The axis of the earth is tilted 66.5 degrees. In summer, the axis leans toward the sun to the maximum degree in the Northern Hemisphere creating warmer and longer days. In winter, the opposite occurs. The solstices, the longest and shortest day, occur June 21 and December 22 respectively. On the spring and autumnal equinoxes, March 22 and September 22, the days are exactly as long as the nights.

The warming of the earth in summer is caused not only by the longer days, but, because of the angle of the earth's axis, solar radiation strikes the earth surface more directly in summer. The winter sun does not strike the earth as directly and therefore does not warm as much as the summer sun. This less direct position also causes the winter sun to be lower in the sky. (See figure 1.)



- Figure 1 -

The various geographic areas of Illinois experience varying temperatures and heating and cooling degree days,* although throughout Illinois the number of cloudy days per month varies little. In general, it can be said that year round it is warmer in the south than in the north and that Chicago is warmer than the area to its immediate west. The coldest average temperature per year is always in the north central and/or northwest part of Illinois.

* Heating degree days are obtained by subtracting the mean daily temperature from 65°F. Cooling degree days are calculated by subtracting 65°F from the daily average temperature.

1) Thermal mass is any material which has the capacity to store heat.

Similarly, there are more heating degree days per year and fewer cooling degree days in the northern part of the state. The opposite is true in the southern part of the state. Heating degree days average 7000 per year on the Wisconsin/Illinois border and 4000 per year in Cairo, Illinois. Cooling degree days average 1700 per year in Cairo and 600 per year in northern Illinois.

Cloudiness has a significant affect on the amount of solar radiation which reaches earth. Even on a clear day the earth's atmosphere prevents 20% of the radiation reaching the outer atmosphere from reaching the earth's surface. In addition to shorter days and a greater sun angle in winter, winter is also cloudier than summer, making winter the most difficult season in which to capture solar radiation. In Illinois it is generally cloudy 17-20 days per month in the winter compared to 9-10 days per month in July.

This is not to say, however, that these are consecutive cloudy days, which may have more adverse impact on the use of solar. From November to May three consecutive cloudy days can be expected twice per month in Illinois. Five to six consecutive cloudy days can be expected once per month in the same time period.

It is also extremely important to realize that some solar technologies can utilize the available solar radiation on cloudy days. Such sunlight is called diffuse solar radiation and is usable on all but very overcast days by most solar collection systems. Other systems can utilize only direct solar radiation (i.e., that which is not obstructed by cloudiness).

THE AFFECT OF THE WEATHER ON THE USE OF SOLAR

Variations in the length of day and amount of cloudiness impact the use of solar differently depending on the type of solar technology being utilized. Certain technologies can take advantage of diffuse solar radiation as well as direct solar radiation, while others can only function with direct solar radiation. In addition, in some systems a storage and/or backup system is necessary while in others, these may not be needed.

Direct sunlight or direct solar radiation is sunlight which is unobstructed by clouds, haze or heavy pollutants. It is the type of sunlight which causes shadows. Diffuse solar radiation is the indirect, scattered sunlight experienced on hazy as well as heavily overcast days. It may cause shadows but they are not crisp and well-defined like those on a very clear day. While no solar device can function in darkness or on very heavily overcast and cold days, some can take advantage of diffuse solar radiation on all but the cloudiest of days. In other words, even though Illinois has many cloudy days, and many consecutive cloudy days, many of the solar technologies are very practical here.

Most solar energy systems have a storage system of some type for those days when solar radiation cannot be used because of heavily overcast skys and for night time use. These storage devices are discussed in the next section. In addition, a backup system run on conventional energy is usually provided for those days and nights that there isn't sufficient sunlight or stored solar energy available.

THE SOLAR TECHNOLOGIES

Passive Solar Energy Systems

Passive solar systems can utilize diffuse solar radiation and thus are very practical in Illinois. It is estimated that well over 800 of these systems presently exist in Illinois. They are used in the residential, commercial, agricultural and industrial sectors. By definition, passive systems utilize little or no conventional energy to operate the system. Instead, energy collection and distribution in passive systems occur by natural means such as convection, conduction and radiation. Passive solar systems may be designed for space heating, space cooling, daylighting or hot water.

Passive solar space heating systems are generally integrated into the design and structural elements of a building. The three types of space heating systems are direct gain, indirect gain and isolated gain systems. Direct gain systems allow sunlight to directly enter the space to be heated where it is used and the excess is stored in floors or walls. In indirect and isolated gain systems, sunlight is converted to heat before entering the living space and then stored or distributed to the living space. All three systems store heat in thermal mass[1)] such as masonry walls or floors, water (in drums, tubes, or a pool, for example) or special salt solutions (eutectic or phase change salts). At night or on very cloudy days, this thermal mass naturally radiates the stored heat into the space to be heated.

Passive solar space heating systems reduce the need for conventional energy for space heating and generally are included during the design stage of a new building or added (retrofitted) on an existing structure. Thus, their use in new or existing structures in Illinois will reduce Illinois demand for natural gas, propane, electricity and oil since these are the fuels commonly used for space heating purposes.

Passive solar space cooling ranges from the simple shading of windows to the more technically complex cool tubes. Shading of solar collection areas (south windows) is commonly accomplished through the use of vegetation or extended roof overhangs on the principle that the summer sun is higher in the sky than the winter sun. Thus, overhangs shade the sun in summer while allowing the winter sun to enter and heat the space.

Solar assisted ventilation is a very effective cooling technique in Illinois. Solar chimneys and cool tubes are two examples of this technique. In essence, they both cool by creating convective air currents in the structure. Cool tubes, draw outside air through an in-earth tube where it is cooled before entering the structure. Solar chimneys are vertical shafts with openings at the top which help induce a draft in a structure even when there is no wind.

Elements of passive heating design such as masonry walls can also help to induce ventilation through the vents and windows used in the heating system. In addition, thermal mass in solar buildings can assist in cooling a structure. The mass which absorbs heat for storage in the winter, can also absorb heat in the summer, then be allowed to release the heat at night. By releasing the heat at night the mass will become cool for the next day when it can absorb the heat again.

Passive solar cooling techniques are not yet as popular as the heating techniques discussed earlier. However, since they help to reduce conventional summer cooling needs, and thus electricity demand, these techniques are likely to become more intentional in years to come.

Daylighting helps to reduce the daytime need for conventional lighting and so is another technique which can reduce electric demand. Through proper placement of windows and skylights, daylighting techniques increase light in a structure while minimizing heat loss in winter and heat gain in summer. No storage is possible in daylighting systems. However, they can utilize very diffuse sunlight. Research and applications in daylighting systems is relatively recent but the potential for these systems is great.

Service hot water (water used for bathing, cooking, cleaning etc.) is an ideal solar application because it is needed year round and generally requires no more than 140°F temperatures. Thus, applications of this type can take advantage of the increase in solar radiation and fewer clouds in the summer.

Passive service hot water systems of the thermosiphon type have been shown to be the most efficient type of solar system for domestic hot water use.

These systems work on the principal that heat rises through convection. Solar collectors are placed below the storage tank. As the water is heated in the collectors it naturally rises to the storage tank. The cooler water in the bottom of the storage tank drops down to the collector to be recirculated.

Batch-type (sometimes called breadbox) and interior collectors are the other two major types of passive service hot water heaters. These two systems are also very effective. They utilize no pumps and are powered by the water main pressure

Active Solar Energy Systems

In contrast to a passive solar energy system, an active solar system requires outside energy to operate the system and to move the collected solar energy from the collector panels to storage and/or for distribution throughout the space. Active solar systems are used primarily for space heating, cooling and hot water. There are well over 1,000 residential, agricultural, commercial and industrial applications of active solar systems in use in Illinois today. The relatively high number of heating degree days (which contributes to a high heating demand) coupled with the predominence of diffuse sunlight makes the use of active solar systems practical in Illinois for both new construction and the retrofit of existing buildings. Active solar systems can provide useable energy on a seasonal (space heating, cooling) or year-round basis (hot water), depending on the application.

Active solar energy systems for both space and water heating primarily use flat plate collector panels to convert sunlight to useable heat. The collector panels themselves can be mounted on the roof or ground or installed vertically on a south facing wall. Basically the collector consists of an insulated box which contains a black metal absorber plate through which liquid can flow or over which air can pass to pick up the collected heat. The collector cover is usually one or two layers of glass or fiberglass that protect the absorber plate from weather and more importantly, keeps the collected heat trapped inside.

The use of active systems requires electricity to operate fans or pumps and any necessary controls to move the collected heat from the panels to storage for later use or directly to the space for immediate use. Active solar energy systems can be used to provide the necessary heat required for such cooling processes, as de-humidification and air conditioning. Common active solar cooling techniques include dessicant cooling and absorption chillers.

The use of active solar energy systems for space heating, cooling and hot water can contribute significantly to reducing Illinois' dependence on all conventional fuels.

Electrical and High Temperature Solar Devices

High temperature solar devices may be used for industrial processes or electrical production. Photovoltaics (solar cells) are solar devices that directly convert sunlight to electricity generally for small scale power needs (residential electric needs, for example).

There are five basic types of solar systems for producing high temperatures. The heat produced by these systems can be used directly for industrial processes or be used to produce electricity for commercial, industrial, residential and agricultural use. The five types are solar ponds, evacuated tube collectors, parabolic throughs, parabolic dishes and central receivers.

The solar pond is a pond which collects solar energy and traps and stores heat within the pond itself by using special purpose salts or by covering the pond. Evacuated tube collectors are basically active solar flat plate collectors with special vacuum tubes which allow the collector to achieve higher temperatures ($212^{o}F$ - $600^{o}F$). The vacuum tube prevents heat from escaping the collector. Unlike the other high temperature solar systems discussed below, both of these systems can utilize diffuse sunlight, making them more practical in Illinois.

Parabolic troughs, parabolic dishes, and central receivers are similar in that they track and focus direct sunlight on a specific point known as the receiver. Without direct sunlight, they cannot operate because they are unable to track diffuse sunlight. Both the parabolic trough and parabolic dish focus sunlight on a receiver located directly in front of them. These systems are often grouped together for combining network of electric wiring or heat transport pipes.

The central receiver or "power tower" differs in design in that sunlight is focused by a series of reflectors on a central tower. The power tower is designed to generate steam or heated air which then acts very similar to a conventional electric power plant in the production of electricity. All three of these tracking and concentrating systems are limited in their practicality in Illinois because the availability of direct sunlight is limited here.

Photovoltaics or solar cells are able to convert diffuse or direct sunlight directly to electricity. Unlike the systems described above, there are no heat transfer mechanisms needed. Sunlight energizes electrons in the cell causing them to move from one side to another, thereby causing a voltage across the cell which is drawn off by electrical wire. Solar cells are usually wired together to form modules or arrays. Excess electricity produced in a photovoltaic array may be stored in batteries or sold to the local electric utility.

Photovoltaic systems can be used in the residential, commercial, industrial, or agricultural sectors to reduce electric demand. While commercially available, photovoltaics are primarily used in remote areas where there are no power lines.

WIND ENERGY RESOURCES IN ILLINOIS

Like solar radiation, available wind energy varies with the time of day and season of the year. In Illinois, wind frequency is greatest during the late winter and early spring. It is also greater in the day than at night. In fact, night wind speed is generally only 30-40% of the speed in the day. Electrical demand in summer is greatest during the day for cooling while in winter, it is greatest during the early evening for lighting. Therefore, wind energy applications can be helpful in meeting electricity demand at its peak.

The wind in Illinois is strongest November through April or May and weakest May or June through October. Average wind speeds per month range from five to 13 miles per hour. Wind speeds also tend to be slower near rough terrain. Thus, in northwestern and southeastern Illinois, wind speeds are slower. The band that stretches from St. Louis in the southwest to Chicago in the northeast tends to experience the fastest wind speeds in the state.

WIND ENERGY TECHNOLOGY

The potential wind energy available is dependant on the air mass and the speed of that air mass*. The energy of motion caused by a moving air mass delivers power which is the rate at which energy is available. Either an increase in air mass (area of the blades) or the wind speed will increase the potential power of wind. The relationship between potential power and wind speed is such that when the wind speed doubles the potential power is cubed (the number obtained when you multiply it by itself three times). Wind speed increases with height (not significantly after 300 feet) and is affected by surrounding structures, vegetation and terrain.

Typically, wind machines were designed for the site with the most wind. Current trends are moving towards developing wind system designs more appropriate to varying geographic wind conditions. As a consequence, there are many different types of systems.

The horizontal axis wind machine with two or more blades is the most popular type machine and possibly the most appropriate for Illinois. In Illinois the majority of locations have fairly constant low-speed winds (from 40% to 50% of the time over ten miles an hour). By manipulating design aspects of a wind machine it is possible to extract a favorable amount of power from this wind. Thus, the smaller amount of power in lower wind speed at a certain height can be increased by increasing the area of the blades and/or the height of the wind machine.

Once wind resource data is available, it is possible to design a system or systems to provide power for residential, commercial, community, industrial, or utility purposes. Power is not available from wind machines when the wind blows below the

generator rated cut-in speed, therefore auxillary power is needed.** The most attractive alternative for a back-up supply is a buy and sell arrangement with the local electric utility. In instances where utility lines are not available, battery storage or hydrogen production via electrolysis are options.

* Air mass is dependant on density and the area captured by a wind machine's blades.

** The wind speed at which the wind machine can begin producing power varies from machine to machine.

SECTION TWO -- Technology Assessment

This section discusses the various solar and wind technologies in depth, including how they work, what they are used for, and how energy from these systems is stored.

I. Passive Solar Space Conditioning

A. Passive Solar Space Heating
B. Passive Solar Space Cooling
C. Daylighting

II. Service Hot Water Systems

A. Active Service Hot Water Systems
B. Passive Service Hot Water Systems
C. Storing Solar Hot Water
D. Solar Swimming Pool Heaters

III. Active Solar Space Conditioning

A. Active Solar Space Heating Systems
B. Active Solar Space Cooling Systems

IV. Photovoltaics

V. Utilization of Solar for Illinois Farms

A. Low Temperature
B. Agricultural Process Heat Applications

VI. High Temperature Solar Process for Industrial Process Heat or Producing Electricity

A. Solar Ponds
B. Evacuated Tube Collectors
C. Parabolic Troughs, Parabolic Dishes and Central Power Towers

VII. Wind Energy Conversion Systems (WECS)

A. Wind Energy Conversion System Design
B. Applications
C. Storage

I. PASSIVE SPACE CONDITIONING

A passive solar energy system is a solar system which is integrated into the design and structural elements of a building. These systems are called passive because unlike active systems, they generally employ no moving or mechanical parts.* Instead, they employ natural radiation, conduction, and convection to condition (cool, heat, or light) space.

While many people think the use of passive solar is only practical to heat new residential structures, its potential uses are much more varied and widely applicable. Passive solar techniques may be used in commercial as well as residential applications for space heating, space cooling, and/or daylighting. Passive systems can be practical for both new construction and the retrofit of existing buildings.

A. Passive Solar Space Heating

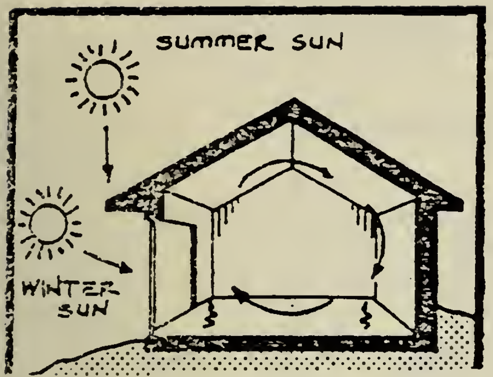
Passive solar space heating systems are either direct gain, indirect gain or isolated gain systems, or a combination of these three. Sometimes one or more of these passive systems are combined with an active solar system. Such active/passive combinations are called hybrid systems and are used to achieve a greater solar contribution. Passive solar systems are generally site built rather than manufactured like many active systems.

* Fans are sometimes used in a passive system to transfer heat.

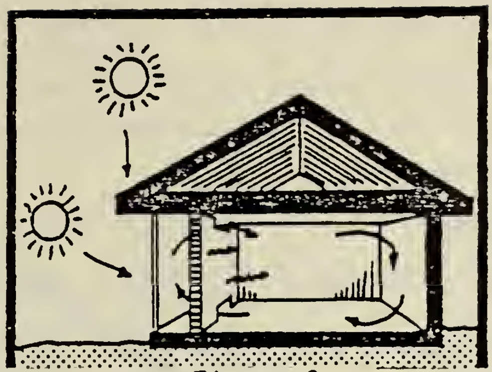
In a direct gain passive solar system sunlight (solar radiation) is admitted directly into the conditioned space through south-facing transparent or translucent apertures or windows (the solar glazing). The solar radiation which enters the space is used in the daytime and any excess is stored in thermal mass. Thermal mass is any building material that has the capacity to store heat such as masonry (floors or walls for example), water (in water drums, tubes, or even a hot tub), or special salt solutions (eutectic salts). At night, this thermal mass releases the stored heat into the space to be heated. It also serves to prevent uncomfortable temperature fluctuations within the space (figure 1).

Masonry walls (sometimes called Trombe walls) or water walls are commonly used in indirect gain systems. In an indirect gain system, thermal mass replaces the conventional south wall and is glazed on the exterior. In the daytime, the useable heat moves into the conditioned space through vents in the mass. At night, the mass naturally radiates the stored heat into the space (figure 2).

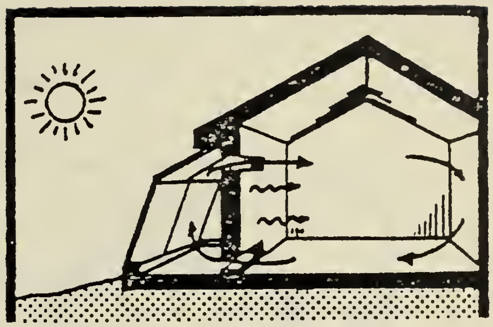
In an isolated gain system solar collection occurs outside the conditioned space, commonly in an attached greenhouse or sunspace. The heat is transferred to the conditioned space by natural convection, or is assisted by fans. The thermal mass for storage is generally located in the isolated gain system, rather than in the conditioned space (figure 3).



- Figure 1 -



- Figure 2 -



- Figure 3 -

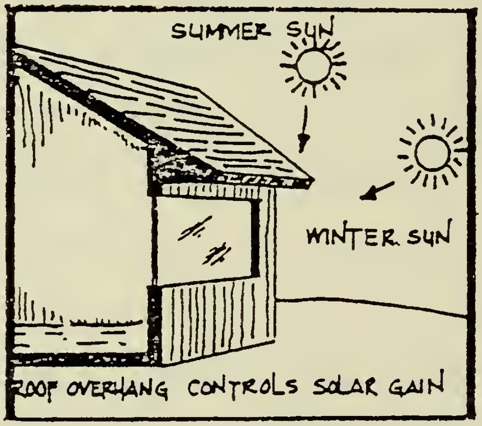
There are important criteria to be considered the design of passive systems. First, the orientation of the structure is important since the passive system will be incorporated into it and the system must face within 20 degrees of due south. Second, the interior layout of the structure is important, since there are usually no mechanical devices to move the heat around the structure. Landscaping can also be important to shade the passive system in the summer when heat gain is to be avoided. Further, to increase heat gain in winter, light colored gravel or concrete to the south can be used to reflect sunlight into the system. Landscaping in the form of wind breaks and earth- berming is beneficial for conservation of energy in any structure, whether it be passive solar, active solar, or conventionally heated.

B. <u>Passive Solar Space Cooling</u>

Passive cooling ranges from the simple shading of windows to the more technically complicated evaporative cooling. For the purposes

of this discussion we will consider shading, natural ventilation, solar assisted ventilation, earth contact and evaporative cooling in the passive solar space cooling category.

Shading to keep space cool can be accomplished with roof overhangs or vegetation. Overhangs of 3-4 feet on the south side of an 8 foot wall are common on passive solar heated homes. Because the summer sun is higher in the sky than the winter sun, overhangs prevent it from entering in summer while allowing winter sun to enter the conditioned space (figure 4). Vegetation such as trees that lose their leaves in winter or annual plants can also be used to shade the structure. However, it is important to note that trees with large or many branches are not recommended because they can substantially reduce solar heat gain in winter.

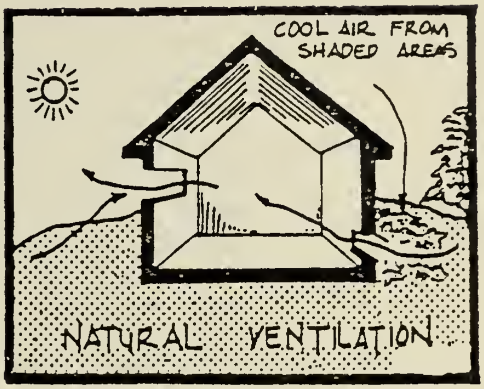


- Figure 4 -

Natural ventilation can cool by creating convective currents. Convective currents can be created by exhaust vents such as clerestories or skylights placed high and intake vents (windows) placed low in a structure (figure 5). In addition, the structure can be oriented to take advantage of summer prevailing winds and landscaping can be done to channel winds (figure 6). Cooler temperatures

gained at night can be stored in the same thermal mass that is used for winter heat storage.

- Figure 5 -



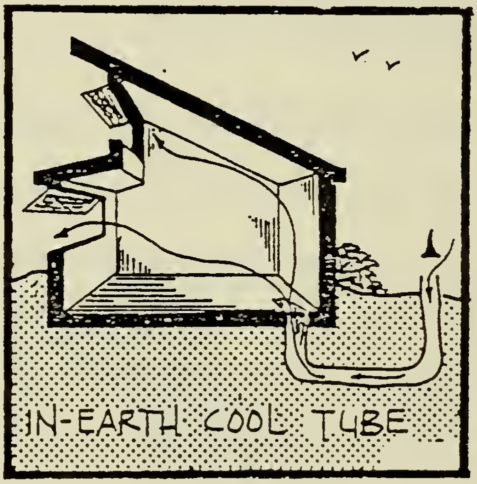
- Figure 6 -

Solar assisted ventilation uses the same principles as natural ventilation. "Solar chimneys" are simply vertical shafts with openings at the top which help to induce a draft in the structure even when there is no wind. In a passive solar system which uses double envelope principles, cool air from the storage under the structure rises through the sunspace and circulates around the house. At night, cool air enters through vents in the sunspace, and drops into the storage, for cooling the next day.

Integrating the building itself with the earth will also help provide summer coolness. As a rule, the more surface area of the house that is in contact with the earth, the cooler it will tend to be in summer. Not only does the earth insulate the structure from

the hot sun, but in addition, the temperature of the earth never reaches outside temperature in the summer, thus helps to cool.

Cool tubes are the popular name given to tubes placed in the earth which cool and dehumidify the outside air before it is drawn into the building. Since the earth's temperature several feet below the surface is a fairly constant 55-60°F, it is possible, through direct contact, to transfer heat from the air into the earth. Cool tubes can be made of materials such as drainage tile, plastic pipe, or concrete or steel culverts (figure 7).



- Figure 7 -

Evaporative cooling is a passive cooling technique which can be used in areas of relatively low humidity. It works on the premise that humidification has a cooling effect when the air is very dry. Since Illinois has a relatively high humidity, evaporative cooling is not practical here and will not be discussed in depth.

C. Daylighting

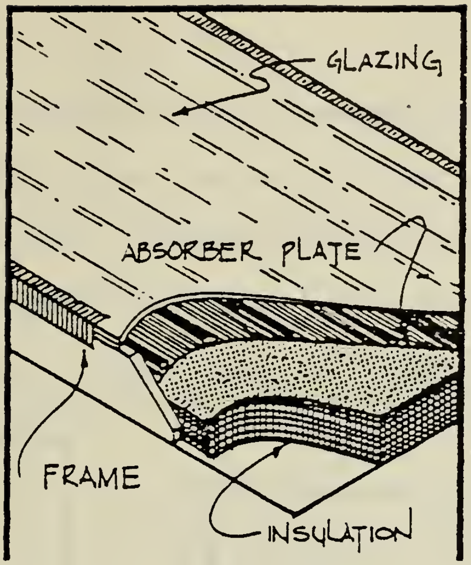
Daylighting helps to reduce the need for conventional lighting through proper placement of windows and skylights. Thus, daylighting along with passive cooling, reduces daytime consumption of electricity. Care must be taken in designing daylighting systems to maximize light gain while minimizing heat gain in summer and heat loss in winter. This can be accomplished through very careful sizing and placement of windows.

II. SERVICE HOT WATER SOLAR SYSTEMS

Service hot water is hot water used for bathing, cleaning, and other uses. In residential or commercial structures the demand for this heated water is year round and generally requires temperatures of no more than 140° F, thereby making service hot water an ideal solar application. Residential and commercial hot water (called domestic hot water for residences) can be provided by medium temperature solar systems. These systems can be active or passive. Low temperature active solar systems can be used to heat swimming pools. These types of systems will be discussed in this section.

A. Active Service Hot Water Systems

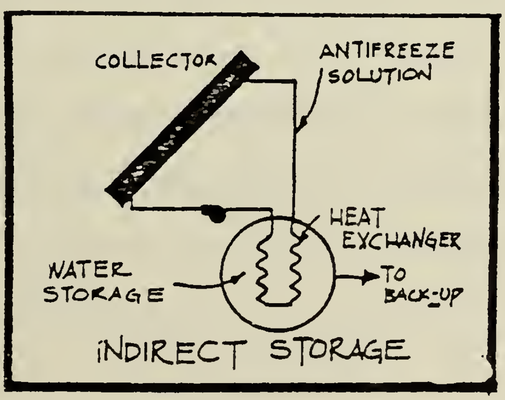
Many manufactured solar hot water systems are available today. The most common type are flat plate solar collectors which consist of an insulated box which contains a black copper or aluminum absorber plate (figure 8). Built into the absorber plate are small channels or tubing through which liquid will flow collecting heat. Covering the front of the collector are either one or two sheets of glass or fiberglass (glazing) which protect the absorber plate from the weather while trapping most of the heat inside. A fluid carries the collected heat to an insulated storage tank where it is held until needed.



- Figure 8 -

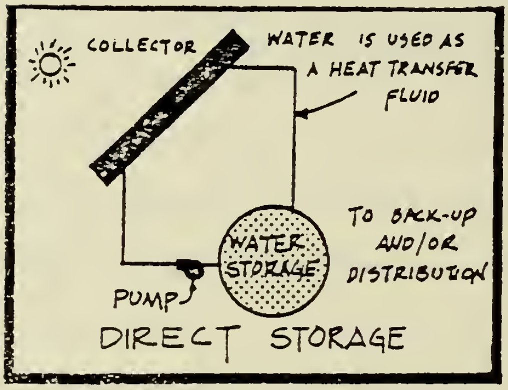
Active hot water systems use electricity to operate pumps and controls. Although some systems use air or freon as the transfer fluid, most systems use water or a water-antifreeze solution. There are basically two types of liquid systems, closed-loop and open-loop. The primary difference between them lies in their method of freeze protection.

Closed-loop systems are used where winters are cold or the water condition is hard. The heat transfer fluid is typically a water-antifreeze solution to provide freeze protection. To transfer the heat from the antifreeze to useable water, a heat exchanger is used. The heat exchanger can be located either inside or outside the solar hot water storage tank (figure 9).

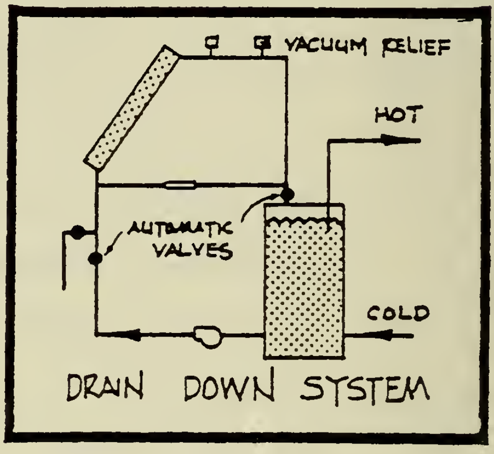


- Figure 9 -

In the open-loop system (also called drain-down or drain-back system), potable water is used as a heat transfer fluid so a heat exchanger is not needed (figure 10). Anytime the collector temperature drops below 38°F the water is automatically drained from the collectors (figure 11).



- Figure 10 -



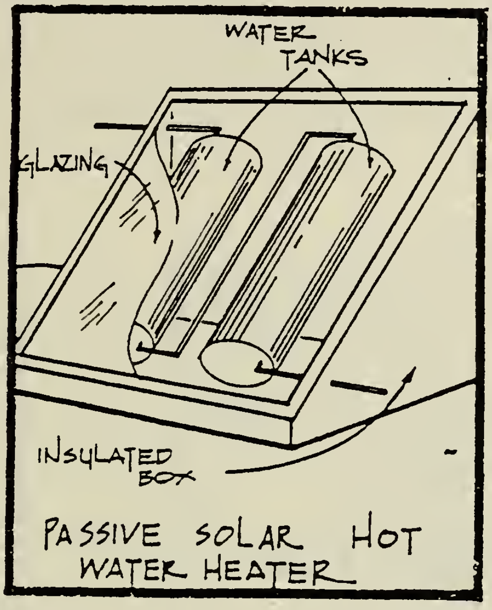
- Figure 11 -

B. Passive Service Hot Water Systems

The most common types of passive solar service hot water systems are the Batch-type system, interior collectors and thermosiphon systems. These passive systems require no electricity and operate by means of natural convection and the power of the water main pressure. None of these systems offers freeze protection.

Batch-type systems (sometimes called breadboxes) are simply one or more holding tanks, painted black, insulated on one side and

installed in a glass or fiberglass covered box. Water from the main enters the tank, is heated by sunlight and drawn from the tank when used. The water from the tank may be used directly or simply pre-heat the conventional service hot water system. These systems are commonly homemade because of their simplicity (figure 12).



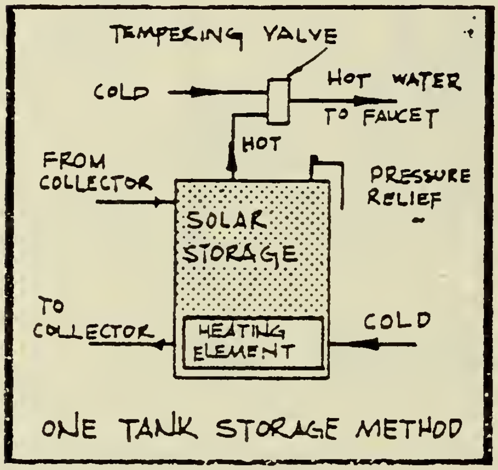
- Figure 12 -

Interior collectors are flat absorber plates located within a heated living space, most commonly a solar greenhouse. In these systems, again, water directly from the water main enters the collectors, is heated, and is drawn off to pre-heat the conventional service hot water heater or be utilized directly. Because they are located indoors, interior collectors require no freeze protection.

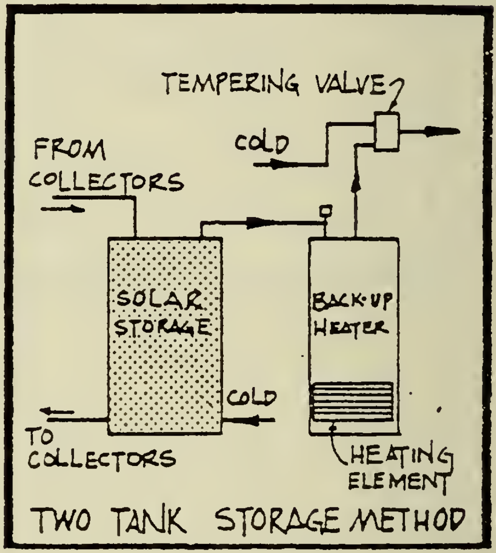
Thermosiphon systems work on the principal that heat rises. Solar collectors are placed below the storage tank and water is pumped into them. As the water is heated it rises into the storage tank above. The hot water is drawn out of the tank as needed. A valve is placed in the pipes to prevent the hot water from draining back into the collectors.

C. Storing Solar Hot Water

Because hot water is commonly needed at nighttime, a storage system is generally used for both active and passive systems. A storage system may consist of a separate storage tank for the solar heated water in addition to the conventional (back-up) service hot water system or the two systems may be combined into one tank (figures 13 and 14).



- Figure 14 -



- Figure 13 -

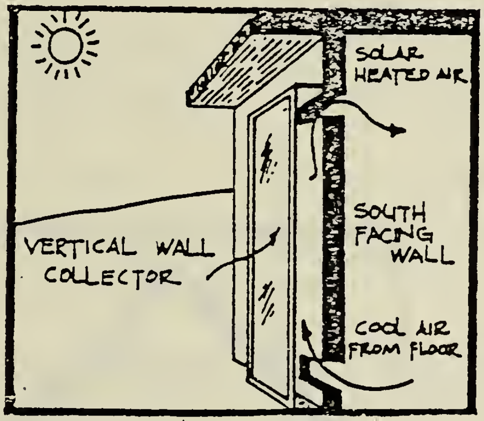
D. Solar Swimming Pool Heaters

Solar swimming pool heaters are generally low temperature active solar systems which help to extend the swimming season by raising the temperature of the pool. They consist of glazed or unglazed flat black absorber plates combined with pumps and controls. Since they are used in the warm seasons of the year, they offer no freeze protection. Given the proper temperature difference between the collectors and the pool, swimming pool water is circulated directly through the collectors, is heated by sunlight and returns to the pool.

III. ACTIVE SOLAR SPACE CONDITIONING

Unlike passive solar systems, in an active solar system the solar collection area is located away from the space to be conditioned. Electric pumps and fans are used to move the collected solar energy from the solar collector to storage and to the space to be conditioned. Active solar systems can provide space heating and cooling as well as service hot water.

There are many designs for active solar systems. Such systems may be manufactured or site-built. Collector panels may be mounted on the roof of a structure or on the ground, or they may be vertically installed on the south side of a structure (figure 15). The medium which transfers heat from the collectors to the structure may be air or liquid.



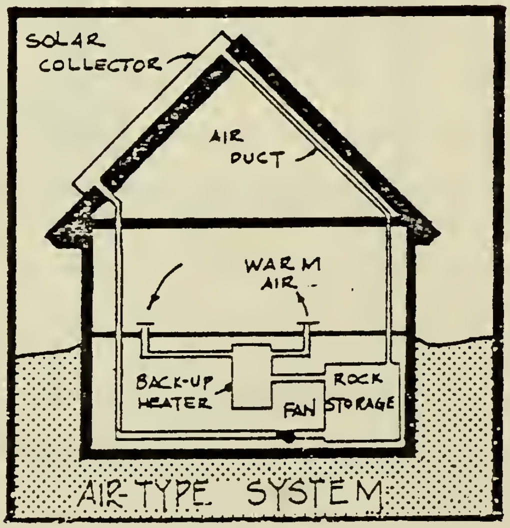
- Figure 15 -

A. Active Solar Space Heating Systems

Active solar space heating systems work by passing a heat transfer fluid, such as air or water, through a solar collector where it is warmed by the sun. This heat is either stored or directly distributed to the house. Thus, an active solar heating system provides for collection, storage and distribution of solar heat.

1. Air Systems

An air system uses air as the heat transfer medium. The collectors consist of a frame, insulation, a metal absorber plate and a glass or plastic cover (glazing). Cool air is passed over or behind the absorber plate where it is heated to approximately 90°F-140°F. The heated air is then sent directly to the house or is stored for later use. Air systems use a fan and air ducts to move air to and from solar collectors (figure 16).



- Figure 16 -

A large wood-framed container filled with small rocks may be used for storing the heat. As the warmed air passes through the container, it gives up its heat to the rocks. The air is then sent back to the collectors to be reheated. When the sun is not shining, heat from the rock storage is used to warm the house. Special salt solutions (eutectic salts) also can be used as heat storage materials.

The movement of solar heated air to the home can be achieved by using a conventional forced-air distribution system. To carry the solar heated air efficiently, the air ducts are often larger than those used for conventional heating systems. This is because the temperature of the solar heated air is lower than air which comes from a conventional furnace.

Some advantages of the air-type space heating systems are:

- no freeze protection is required;
- system leaks will not cause property damage;
- less mechanical equipment is required than liquid-type systems;
- less maintenance is required than for liquid-type systems;
- the system does not corrode.

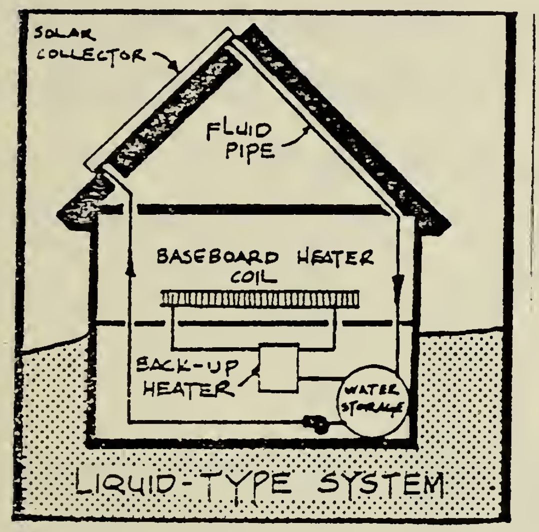
2. Liquid Systems

Liquid systems use water or an antifreeze solution as the heat transfer fluid. The fluid passes inside or on top of the absorber plate where it absorbs the solar heat captured by the collector. In cold climates, some kind of freeze protection is required to prevent the heat transfer fluid from freezing and possible damaging the collectors. Freeze protection can be provided by either completely draining the fluid from the collector or by circulating an antifreeze solution.

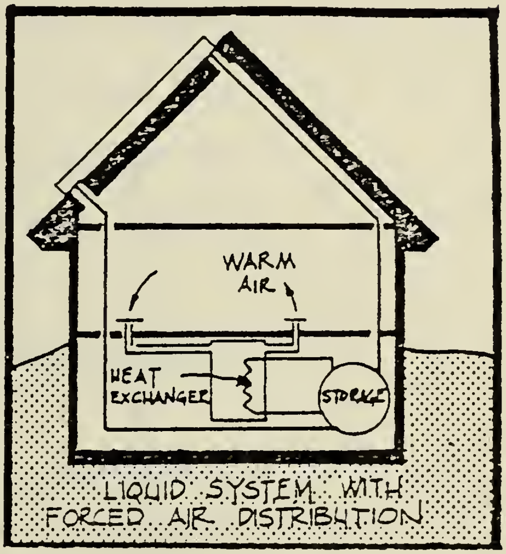
In most liquid systems an insulated tank filled with water stores the solar heat. The heat is stored either directly or indirectly. The direct storage method is used when the heat transfer fluid is water. This approach simply mixes the warmed water from the collectors directly with the water in the storage tank. Freeze protection is provided by automatically draining the water from the collectors. Thus, this type of system is called an open-loop or drain-down system.

The closed-loop method keeps the antifreeze solution, often used in collectors, from mixing with the water in the storage tank. To do this, a heat exchanger is placed inside or outside the storage tank. The warmed fluid from the collector is passed through the heat exchanger where it gives up its heat to the water in the storage tank.

The heat from storage can be distributed several ways. Water can be circulated through fan-coil radiator-type units, radiant panels or baseboard radiator-type heating coils (figure 17). Another method places a water-to-air heat exchanger in a forced-air distribution system (figure 18).



- Figure 17 -



- Figure 18 -

Advantages of liquid systems are:

- the storage tank size may be smaller than the storage used for an air-type system;
- for existing homes, a liquid system may be easier to install than an air system with larger air ducts; and
- the two or three small pumps may require less electrical energy for operation than fans for the air-type systems.

B. Active Space Cooling

1. Dessicant Cooling

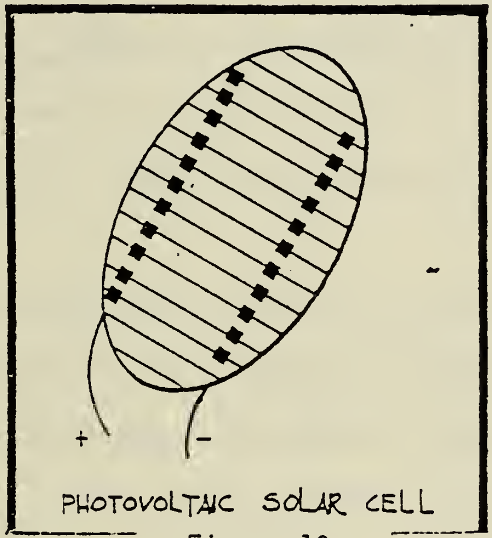
Removing humidity will serve to cool an environment. Dessicant materials can absorb humidity and hence cool the air entering a building. In a dessicant cooling system, passive or active solar systems providing low temperature heat "recharge" dessicant material by drying, so the dessicant can absorb more moisture. The dry air is then used to cool the building.

2. Absorption Chiller

An absorption chiller delivers the same quality cooling as a conventional air conditioner and works on the same similar principles. Whereas a conventional air conditioner is powered by an electric motor to produce a heat source, absorption chillers use a direct heat source. An absorbtion chiller can be powered by using a solar collector as the heat source. This "powering" requires a high enough temperature fluid to heat a refrigerant in the absorption chiller causing it to vaporize. This vapor under pressure is driven into a condensor where it condenses under a different pressure. The condensed fluid evaporates to cool a water circuit. This chilled water is then used to cool the building.

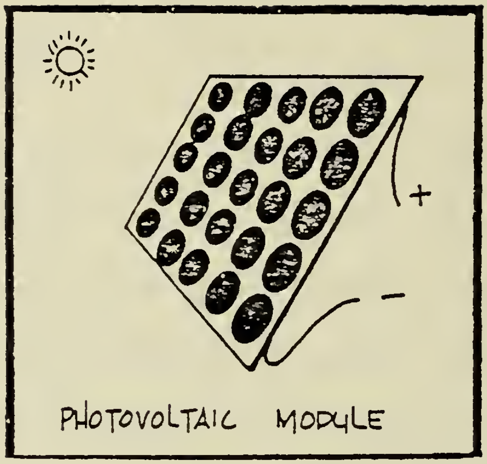
IV. PHOTOVOLTAICS

A photovoltaic cell or solar cell is a solar device which produces electricity. It is typically made of a semi-conductor material which produced electricity when struck by sunlight. The sunlight energizes the electrons in the cell causing them to move from one side to another which, in turn, causes a voltage across the cell, which is drawn off by electrical wire (figure 19).



- Figure 19 -

The electrical energy available from a single cell is very low. Thus, photovoltaic cells are generally wired together to form modules or arrays (figure 20). Complete photovoltaic systems consist of the array, power conditioning for controlling and regulating the electricity produced (DC-AC converters, voltage regulators, etc.), a distribution device, and sometimes a storage device.



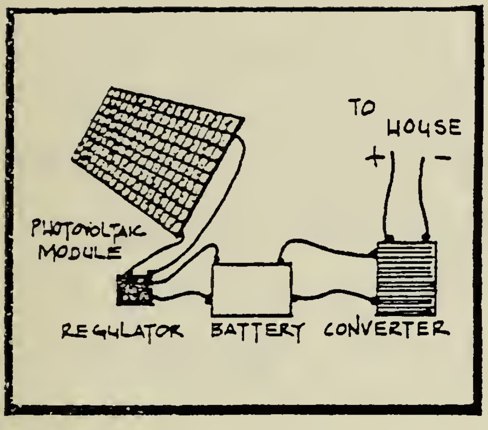
- Figure 20 -

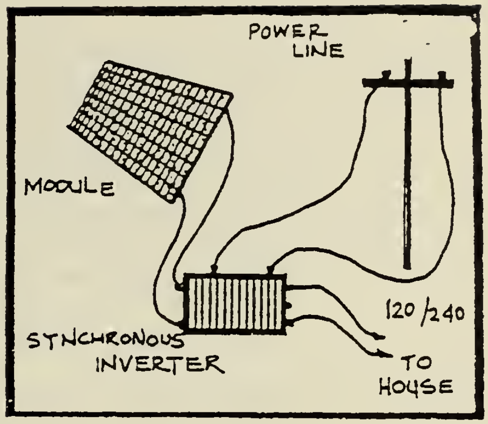
Several types of semi-conductor materials may be used in photovoltaic cell production. While silicon is most common, selenium, gallium arsenide, cadmium telluride and copper sulfide may also be used.

Photovoltaic arrays, like other solar devices, are placed facing south. They may be mounted on the roof, ground, or on the side of a structure. They may be used in residential, commercial, or industrial structures, since all three of these use electricity.

Electricity generated by photovoltaic cells may either be stored or sold to the local electrical generating facility. Batteries may be used to store the electric power generated. However, it is important to note that only direct current (DC) can be stored. Thus, a DC/AC converter is usually needed to change the stored energy to useable alternating current (AC) for use in the structure (figure 21). Alternatively, power may be converted to AC and sold to the power company (figure 22). The Public Utilities Regulatory Policies Act of 1978 (PURPA) requires that utilities purchase power from small generating facilities such as photovoltaic arrays.

Figures 21 and 22





V. UTILIZATION OF SOLAR ENERGY FOR ILLINOIS FARMS

A. Low Temperature

Solar collectors incorporated into the walls and roofs of farm buildings can provide a low cost source of heat for drying crops, warming animal shelters, ventilation air, and/or heating a building. There are many different ways that a solar collector can be built into a farm building but the four basic approaches used to incorporate a collector into a farm building are: 1) covered plate solar collector, 2) attic solar collector, 3) half-attic solar collector, and 4) passive solar collector.

The construction of a covered plate solar collector is similar to many solar panels since it has a solar absorber surface located close to the clear cover material (less than 12 inches) creating a definite channel through which air to be solar heated is pulled. This method of incorporating a solar collector into a building creates the most efficient collector of those mentioned above, but is generally more difficult to build.

An attic solar collector is formed by replacing the south half or the east/ west halves of a metal building roof with a transparent roofing material and then creating an attic by attaching a sheathing material to the underside of the building trusses. Sunlight

shining into this attic area will heat the attic portion of the building. The solar heated air can be pulled out of the attic and be used for drying grain and other crops or space heating. The main advantage of the attic collector is its simplicity. It is not as efficient as a narrow air passage covered plate collector and has the disadvantage of subjecting wooden trusses to extreme temperatures. Such exposure can lead to deterioration of the trusses unless care is taken to properly ventilate the attic in the summertime.

Similar to the attic collector, in the half attic solar collector the attic is partitioned so air is moved through only half the attic space. The half attic solar collector is slightly more efficient than the complete attic collector and it also helps eliminate the water condensation problems associated with some attic collectors.

A passive solar building is created by replacing the south metal wall and/or roof slope of a building with a clear cover material. Sunlight shining into the building heats the building and its contents passively. The warmed air within the building can be actively removed and ducted for use elsewhere. This is the simplest solar system to build for on farm use.

Many agricultural buildings, because of their large surface areas subjected to the direct rays of the sun, can provide energy for farmstead processes. Solar energy collected by flat plate solar collector incorporated into agricultural buildings can be a practical source of heat energy for drying agricultural crops. Solar crop drying systems also function exceptionally well when used in combination with more conventional drying methods, i.e., solar drying can be used to complete the drying of grain following partial moisture reduction in a high temperature fossil fuel fired dryer. Solar energy collection systems designed into buildings for crop drying can also become multiple use systems by supplying winter heat for shops and livestock shelters.

B. Agricultural Process Heat Applications

Flat plate collectors can provide heat for dairy operations and other agricultural applications requiring up to approximately 150°F above outdoor (ambient) temperatures. The heat from the solar collector is moved into the process directly or through heat exchangers, with or without storage, and with or without conventional back-up power, depending upon the system design.

VI. HIGH TEMPERATURE SOLAR PROCESSES FOR: INDUSTRIAL PROCESS HEAT OR PRODUCING ELECTRICITY

Introduction for Industrial Process Heat--Electricity

There are five basic types of solar collectors for producing high temperatures. These are solar ponds, evacuated tube collectors, parabolic troughs, parabolic dishes and central receivers.

A. Solar Ponds

While any pond collects heat, the solar pond is unique in the fact that they artificially inhibit heat loss thereby effectively collecting solar energy and converting it into usable low-temperature heat, or high temperature heat to be used directly or to produce electricity. In essence, solar ponds act as both the collector and storage.

There are essentially two categories of solar ponds. One type of solar pond traps the solar heat by covering the top of the pond, the source of major heat loss. The other type of solar pond traps the heat within the storage medium (the pond itself) typically by using special purpose salts, or other materials which inhibit heat loss. A combination of these two is possible in the design and use of a solar pond.

B. Evacuated Tube Collectors

Evacuated tube collectors are essentially flat plate collectors designed to take special care in preventing heat loss through the heat transport tubes within the collector. These tubes are coated with a selective absorbing surface and sealed with special light admitting glass to duplicate a vaccum tube. It is this special absorbing tube within a glass tube which allows for a higher temperature inside the collector. A special heat transfer fluid is circulated through the evacuated tube collectors because they can reach temperatures ranging from 212°F-600°F. Since the evacuated tube collectors are placed in a flat plate collector design it is not necessary they follow or track direct sunlight. Some evacuated tube collectors have reflective material around three sides of the tubes for concentrating the sunlight on the tube. With these temperature ranges, the evacuated tube collector is applicable to only intermediate temperature process heat applications.

C. Parabolic Troughs, Parabolic Dishes, and Central Power Towers

Parabolic troughs, parabolic dishes and central power towers use the same basic theory in capturing solar energy to create very high temperatures (600°F and up). This heat may be used directly or be used to make electricity. The similar design element is that all three technologies follow or track the sunlight and focus or

concentrate sunlight by reflecting it on a specific area known as the receiver.* The major concern in using these technologies is the absolute requirement of direct, clear sunshine, because without it these technologies cannot operate.

These technologies differ in their design for focusing the solar energy on the receiver and the resulting end temperatures. Simply put, a parabolic trough is a rectangular reflective material geometrically shaped to focus sunlight onto an absorbing tube which is parallel in front of the trough. A special gas is circulated through the tube and used to obtain high temperatures or to produce steam for electric production.

A parabolic dish, as the name implies, is a dish-shaped reflector which concentrates sunlight on the receiver which is located in front of the dish. The parabolic dish, like the trough, can use the high temperature directly for an industrial process or electric production. Both the dish and trough can be grouped together for combining a network of electric wiring or heat transport pipes. As with all concentrating systems, tracking of the sun is necessary, and is usually automated by complicated mechanical equipment.

* (Note: In some instances special lenses are used to concentrate light on a receiver, similar to the optic effects of a magnifying glass.)

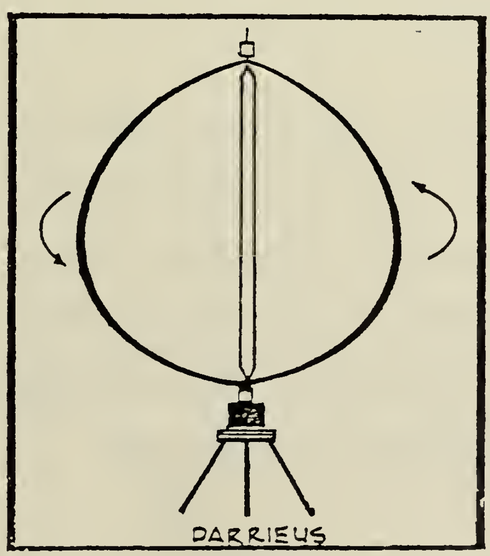
The central power tower, which also tracks and reflects sunlight, differs in its design by focusing the solar energy on a central tower. The power tower is designed to generate steam or heated air which then acts very similar to a conventional electric power plant in the production of electricity.

VII. WIND ENERGY CONVERSION SYSTEMS (WECS)

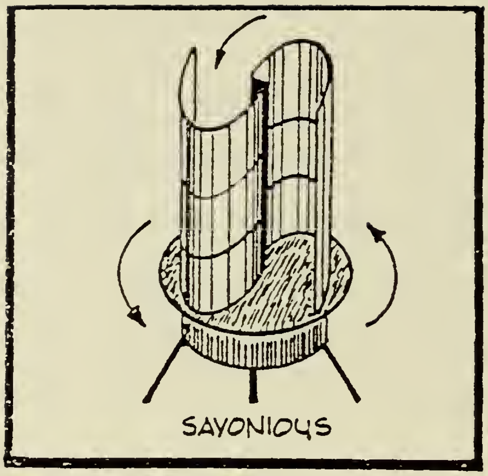
Wind is caused by the sun's uneven heating of the earth. Wind turbines use power from the wind when their rotors (blades) are pushed around by moving air capturing the kinetic energy or energy of motion from the wind. The rotors process the energy in the wind and convert it into mechanical power. This mechanical power can be used to turn a generator which will produce electricity.

A. Wind Energy Conversion Systems (WECS) Design

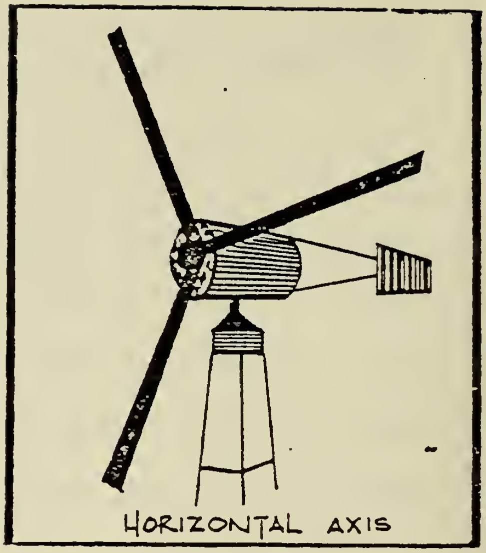
There are basically two types of WECS which are characterized by their axis, either horizontal or vertical. Vertical axis wind turbines of Darrieus type look like giant egg beaters (figure 23). Darrieus wind turbines are quite efficient at high wind speeds but operate poorly at lower to medium wind speeds. The Savonions wind turbine is another vertical axis machine and is quite powerful at fairly low speeds (figure 24). Horizontal axis WECS model the typical windmill design which were used for pumping water in rural applications. Horizontal axis WECS are the most popular types and typically have two or three blades, although they may have more (figure 25).



- Figure 23 -



- Figure 24 -



- Figure 25 -

The performance of a WECS is affected by the generator size, the wind speed, the rotor span (area covered by the blades) and the overall system efficiency. Since wind speed increase with height, and power or energy increases with wind speed, the height of the wind system effects the performance also. Generators for wind systems can range from less than one kilowatt (1,000 watts) to a megawatt (a million watts) or more. Rotor spans can vary significantly too, from less than 12 feet in diameter to over 175 feet in diameter.

B. Applications

Generally wind turbines are used for producing electrical energy. The electrical energy produced by WECS can be used in the residential, commercial, industrial or utility sector. In other words, it substitutes for conventional electricity by producing AC or DC current. Wind Energy Conversion systems can be located individually or in groups known as wind farms.

C. Storage

Wind is an intermittant source of power so its availability may not always match up with the demand of the electric load (appliance requirement). This situation makes storage necessary for wind energy conversion systems in practically all applications. Possibilities for storage with wind systems include batteries, electric utility interconnection, or hydrogen production by electricity.

SECTION THREE: Glossary of Terms

Absorber - the surface in a collector that absorbs solar radiation and converts it to heat energy; generally a matte black metallic surface is best.

Absorption chiller - air conditioning device which uses heat at 190°F or higher to generate cooling; it may be powered by solar-heated water.

Active solar energy systems - in contrast to passive solar energy approaches, an active solar energy system utilizes outside energy to operate the system and to transfer the collected solar energy from the collector to storage and distribute it throughout the living unit. Active systems can provide space heating and cooling and domestic hot water.

Air-type collector - a collector that uses air for heat transfer.

Ambient temperature - natural temperature surrounding an object; it usually refers to outdoor temperature.

Auxiliary heat - the heat provided by a conventional heating system for periods of cloudiness or intense cold, when a solar heating system cannot provide enough heat.

Backup energy system - a backup energy system using conventional fuels should be provided for heating and domestic hot water. This system should be capable of providing all of the energy demand during any period when the solar energy system is not operating. Components and subsystems may be used as parts of both systems where the component or subsystem is a recognized, acceptable product in the conventional building industry.

British thermal unit (BTU) - a unit of heat; the quantity needed to raise the temperature of one pound of water one degree Fahrenheit.

Building envelope - the elements (walls, roof, floors) of a building which enclose conditioned spaces.

Clerestory - a window located high in a wall near the eaves, used for light, heat gain, and ventilation.

Collection - the process of trapping solar radiation and converting it to heat.

Collector - a device which collects solar radiation and converts it to heat.

Collector aperture - the glazed opening in a collector which admits solar radiation.

Collector efficiency - the ratio of the heat energy extracted from a collector to the solar energy striking it.

Concentrating collector - a collector with a lens or a reflector that concentrates the sun's rays on a relatively small absorber surface.

Conduction - the flow of heat between a hotter material and a colder material that are in direct physical contact.

Convection, natural - the motion of a gas or liquid, caused by temperature or density difference, by which heat is transported.

Cover plate - a layer of glass or transparent plastic placed above the absorber plate in a flat-plate collector to reduce heat losses.

Degree-day - a unit of measurement for outside temperature; it is the difference between a fixed temperature (usually 65°F (18°C)) and the average temperature for the day.

Diffuse radiation - indirect scattered sunlight which casts no shadow.

Direct radiation - sunlight which casts shadows, also called beam radiation.

Direct solar gain - a type of passive solar heating system in which solar radiation passes through the south-facing living space before being stored in the thermal mass for long-term heating.

Distribution - the movement of collected heat to the living areas from collectors or storage.

Double-glazed - covered by two layers of glazing material (commonly, glass or plastic).

Drainback - a type of liquid heating system which is designed to drain into a tank when the pump is off.

Draindown - a type of liquid heating system which protects collectors from freezing by automatically draining when the pump is turned off.

Earth berm - a mound of dirt that abuts a building wall to stabilize interior temperature or to deflect the wind.

Eutectic salts - a mixture of two or more pure materials which melts at a constant temperature; a material which stores large amounts of latent heat.

Evaporative cooling - a method of space conditioning which requires the addition of bodies of water or of moisture for cooling the living spaces.

Flat-plate collector - a solar collection device in which sunlight is converted to heat on a flat surface; air or liquid flows through the collector to remove the heat.

Forced-air heat - a conventional heating distribution system which uses a blower to circulate heated air.

Glazing - a material which is translucent or transparent to solar radiation.

Greenhouse - in passive solar design, an attached glazed area from which heat is withdrawn to the living space during the day.

Heat gain - as applied to heating or cooling load, that amount of heat gained by a space from all sources (including people, lights, machines, sunshine,etc.).

Heat transfer - conduction, convection, or radiation, or a combination of these.

Heating load - the rate of heat flow required to maintain indoor comfort; measured in BTU per hour.

Hybrid solar energy system - a hybrid system is one incorporating a major passive aspect, where at least one of the significant thermal energy flows is by natural means and at least one is by forced means.

Indirect gain solar - a type of passive solar heating system in which the storage is interposed between the collecting and the distributing surfaces (e.g. Trombe wall, water wall, or roof pond).

Insolation - the amount of solar radiation (direct, diffuse, or reflected) striking a surface exposed to the sky; measured in BTU per square foot per hour (or in watts per square meter).

Isolated solar gain - a type of passive solar heating system in which heat is collected in one area to be used in another (e.g., greenhouse or attic collector).

Life-cycle cost analysis - the accounting of capital, interest, and operating costs over the useful life of the solar system compared to those costs without the solar system.

Liquid-type collector - a collector that uses a liquid as the heat transfer fluid.

Nocturnal cooling - a method of cooling through radiation of heat from warm surfaces to a clear night sky.

Passive solar energy systems and concepts - passive solar heating applications generally involve energy collection through south-facing glazed areas; energy storage in the building mass or in special storage elements; energy distribution by natural means such as convection, conduction, or radiation with only minimal use of low-power fans or pumps; and a method controlling both high and low temperatures and energy flows. Passive cooling applications usually include methods of shading collector areas from exposure to the summer sun and provisions to induce ventilation to reduce internal temperatures and humidity.

Payback - the time needed to recover the investment in a solar energy system.

Percent possible sunshine - the amount of radiation available compared to the amount which would be present if there were no cloud cover; usually measured on a monthly basis.

Photovoltaic cell - a device without any moving parts that converts light directly into electricity by the excitement of electrons.

Preheat - the use of solar energy to partially heat a substance, such as domestic potable water, prior to heating it to a higher desired temperature with auxiliary fuel.

Radiation - the process by which energy flows from one body to another when the bodies are separated by a space, even when a vacuum exists between them.

Refrigerant- fluid, such as Freon(R), that is used in heating or cooling devices, such as heat pumps, air conditioners, or solar collectors.

Reradiation - the emission of previously absorbed radiation.

Retrofit - to modify an existing building by adding a solar heating system or insulation.

Selective surface - a surface that is a good absorber of sunlight but a poor emitter of thermal radiation; used as a coating for absorbers to increase collector efficiency.

Solar collector - a device which collects solar radiation and converts it to heat.

Solar fraction - the percentage of a building's seasonal heating requirement provided by a solar system.

Solar gain - the part of a building's heating load, or an additional cooling load, which is provided by solar radiation striking the building or passing into the building through windows.

Solar radiation - energy radiated from the sun in the electromagnetic spectrum; visible light and infrared light are used by solar energy systems.

Solar thermal electric power - the indirect conversion of solar energy into electricity by solar collectors, a heat engine, and electrical generators.

Solarium - a living space enclosed by glazing; a greenhouse.

Stack effect - the rising of heated air over a dark surface by natural convection to create a draft; used to provide summer ventilation in some passive houses.

Storage - the device or medium that absorbs collected solar heat and stores it for later use.

Sunspace - a living space enclosed by glazing; an solarium or greenhouse.

Thermal mass - the heat capacity of a building material (brick, concrete, adobe, or water containers).

Thermosiphoning - heat transfer through a fluid (such as air or liquid) by currents resulting from the natural fall of heavier, cool fluid and rise of lighter, warm fluid.

Tracking - for a collector, a device which causes the panel to follow the sun.

Transfer medium - the substance that carries heat from the solar collector to storage or from storage to the living areas.

Trombe wall - masonry, typically 8 to 16 inches thick, blackened and exposed to the sun behind glazing; a passive solar heating system in which a masonry wall collects, stores, and distributes heat.

ILLINOIS
BIOMASS RESOURCE SUMMARY
AND TECHNOLOGY ASSESSMENT

CONTENTS

INTRODUCTION

Biomass is a scientific term for any material derived from growing organisms. Biomass, from an energy standpoint, is organic material produced by living organisms such as trees, crops, manure, combustible solid wastes, and plants which can be converted to usable forms of renewable energy. Biomass energy is derived from solar energy because all organic matter depends on sunlight and the process of photosynthesis. Biomass energy can be released through a variety of biological and thermal conversion processes to produce energy and fuels such as alcohols, methane, synthetic gas and oils, heat, steam, and electricity. Renewable biomass energy sources can meet specific energy needs while reducing the use of conventional fuels.

Historically, biomass was utilized extensively in the form of wood for home heting and industrial purposes prior to the advent of abundant and inexpensive fossil fuels. Today in Illinois, wood is making a considerable comeback as a residential heating fuel. In addition, alcohol fuels, such as ethanol produced from the biological fermentation of agricultural crops are being used as a transportation fuel in the form of gasohol.

Nationally, biomass contributes slightly over 2 quads (2 quadrillion Btu's) to our national energy use of approximately 71 quads. While this is a small figure in comparison to natural gas and oil consumption, biomass utilization for energy in the United States is domestically produced, renewable, and an ideal feedstock for supplying cost competitive energy in a number of applications.

EXISTING USES OF BIOMASS FOR ENERGY IN ILLINOIS

Bioconversion in its many forms has experienced recent growth and commericial realization in Illinois. Most notably, the popularity of wood for residential heating and ethanol in the form of gasohol for vehicle fuel are the two most common uses of biomass resources indigenous to Illinois.

Countless thousands of cords of firewood are consumed in Illinois to fuel stoves and fireplaces for heating each year: a trend which has increased dramatically in Illinois as well as the nation as a whole. Residential wood heating is becoming a secondary heating source for a substantial number of Illinois homes, and is emerging as a primary heating source for a growing number of residences as well.

Gasohol, a blend of 10% anhydrous ethanol and 90% unleaded gasoline, is marketed by 500-600 service stations in the state. Annualized gasohol sales were 68.7 million gallons in 1980. Illinois has become a leader in the production of ethanol, the renewable liquid fuel component of gasohol that is produced by the fermentation of agricultural biomass crops. In Illinois, corn is the predominant feedstock, although a small quantity of ethanol is being produced from food processing waste products, including dairy whey, confectionary sugars and candy wastes. Over 55 million gallons of commercial anhydrous ethanol were produced in Illinois in 1980. New commercial plants under construction are expected to increase total production to about 195 million gallons per year in 1982.[1] This new production capacity will utilize approximately 75 million bushels of grain (primarily Illinois corn)

[1] Alcohol Fuels Program Statistics, Biofuels Section, Illinois Institute of Natural Resources.

and produce a number of food products for human and livestock consumption as by-products.

Solid waste, produced by municipalities and industry, is another biomass resource which is beginning to be utilized for energy at several sites in Illinois. Since the early 70's, the City of Chicago has operated two facilities for processing solid waste to extract combustible materials which are burned to produce steam for industrial use. One facility, the Northwest Incinerator Plant is combusting 1,600 tons per day of refuse to produce steam, which is sold to the Brach Candy Company. Several industries and institutional facilities are investigating the mass firing on-site of combustible solid waste streams they generate, in order to convert their waste streams into heat and steam.

Another technology which is being applied in Illinois is the recovery of methane from existing sanitary landfills and sewage treatment plants. One such project in Calumet City is tapping a landfill to produce several million cubic feet per day of pipeline quality methane. The methane recovered is fed into a conventional natural gas pipeline for use by residential and commercial needs. The Chicago Metropolitan Sanitary District is recovering 2.7 million cubic feet of digester annually from their West-Southwest Sewage Treatment Plant.

Several sawmills and wood processing industries in the state are using the wood wastes and sawdust they generate for meeting a portion of their energy needs. One sawmill near Cairo uses sawdust to dry lumber in their kiln, thus solving a waste disposal problem and the need for natural gas for lumber drying.

Agriculture in Illinois is also turning to biomass as an alternative source for on-farm energy requirements. Several confinement livestock operations have installed anaerobic digestion systems to produce methane from cattle and poultry manure. The methane generated by anaerobic digestion can be utilized on-site for electrical generation, supplying heat to farm buildings, or as a boiler fuel for a small alcohol plant. Several farmers are also utilizing the biomass residues available from their fields for grain drying. Corn cobs, bales or stacks of cornstalk residues, straw or hay are combusted in a residue furnace to produce heat for drying grain, thus saving the farmer on fuel costs for propane. The DeKalb Seed Company has developed an experimental 6 MBtu gasifier for drying of seed corn which uses corn cobs as a feedstock.[2]

A number of other applications for biomass conversion are under investigation or development in Illinois. Biomass, in its many forms, will not likely become the dominant energy source for all energy consuming sectors of the state's economy. Biomass will, however, continue to be a viable alternative for a number of specific applications where fossil fuel use can be replaced.

Biomass Resources Availability in Illinois

The state of Illinois contains a significantly diverse and abundant biomass resource base. The fertile soils and favorable topography and climate of Illinois provide an ideal environment for biomass production and potential conversion to renewable fuels and energy. In general, these biomass sources may be divided into six categories, each of which will be discussed in further detail:

[2] Feasibility of Small-Scale Biomass Combustion Systems for On-Farm Grain Drying, IINR.

1. wood and wood residues,
2. conventional agricultural corps,
3. agricultural crop residues,
4. farm livestock/human organic wastes,
5. urban and industrial combustible wastes, and
6. special energy crops

Wood and Wood Residues

Of the numerous types of biomass resources which can be converted to energy, wood is the most commonly utilized and best recognized source. Thousands of Illinois citizens rely on the availability of wood, collected from forested land, urban tree trimming operations, or other wood sources, to supply fuel for residential heating.

The state of Illinois contains approximately four million areas classified as commercial forested land. In a state largely dominated by agricultural and urban land uses, our forested land resources are small by comparison. Over 94% of commercial forest land in Illinois is under private ownership in parcels of ten acres or less, and in need of forest management improvement techniques.[3] Geographically, commercial forested land is primarily located in southern and western portions of Illinois. Non-commercial wooded land, which supplies a major source of fuel wood, is scattered throughout the state. This type of wooded land is concentrated as mixed tree growth in bottom lands, right-of-ways, and hilly and sloping non-agricultural land. Wood and wood residues resources can be divided into cordwood, sawmill residues, forest residues, and wood processing wastes. Unfortunately, little

[3] Illinois Department of Conservation, Division of Forestry Statistics.

data is currently available on the quantities of wood and wood residues available for energy. One study done by the City of Chicago, Bureau of Forestry, estimated that in 1975 about 40,000 tons of wood wastes were produced from tree trimming operations in Chicago alone.[4] A study on the consumption and availability of fuel wood in Illinois may be undertaken by the State in the near future.

Agricultural Crops

Illinois is the leading agricultural state in the Nation with over 80% of Illinois' 36 million acres in farmland. The major field crops of Illinois are corn, soybeans, wheat, oats and hay. Corn is the chief crop, with its harvested value close to one half of all crops in the state. A recent three year average showed that approximatley 10.7 million acres were planed in corn, with about 1.2 billion bushels harvested.[5] Corn is an excellent biomass crop, producing starch in the corn kernels that can be fermented to ethyl alcohol, and cellulose, hemicellulose, and lignin in the rest of the corn plant that can be thermally or biologically converted to a variety of energy forms. In Illinois, corn is the predominate feedstock for commercial and farm-scale ethanol production. Anticipated commercial ethanol production in Illinois in 1982 will utilize 75 million bushels of corn, primarily from Illinois. Modern commercial wet and dry milling of corn, in addition to producing anhydrous ethanol for fuel or industrial uses, produces a number of by-products. These include corn oil, fructose sugar, corn gluten meal, and other food and fiber products for human and livestock consumption.

[4] Utilizing Urban Tree Debris and An Analysis of Alternatives for Chicago, Illinois. Chicago Department of Streets and Sanitation, Bureau of Forestry.
[5] Illinois Department of Agriculture Statistics.

The agricultural processing industry is well represented in Illinois, ranking second only to California. This industry produces a variety of annual crops including corn, soybeans, wheat and seasonal crops such as sweetcorn, snap-beans, asparagus, apples, peaches and other vegetables and fruits. The waste streams from agricultural processing industries can technically be convereted to energy, often with added benefits of reducing pollution control requirements. High moisture waste streams are best suited for conversion to methane or alcohols. Some solid waste products can be thermally converted to heat or steam. Estimates for Illinois place the quantity of vegetable processing wastes at over 400,000 tons, of which at least 13,000 tons have no directy by-product use. The production of dairy products produce approximately one million pounds of liquid dairy whey. A small portion of this waste stream is currently being used as a feedstock for ethanol production.

Agricultural Crop Residues

The quantity of crop residues generated annually in Illinois is perhaps the highest of any state in the U.S. Crop residues are the predominant biomass resource in Illinois in theoretical quantity, generating about forty million dry tons annually. However, necessary and competing uses of crop residues for their fertilizer values, soil development and erosion control, and forage values, limit residue availability for bioconversion. Perhaps as much as 23 million tons annually may be suitable for energy conversion, although the costs of collection, handling, storage and processing limit the feasible utilization of residues to decentralized applications.[6] Agriculture, in

[6] Illinois Biomass Resources: Annual Crops and Residues; Canning and Food Processing Wastes - A Preliminary Assessment Developed by Argonne National Laboratory for the Illinois Institute of Natural Resources.

the future, may adopt biomass residues, such as straw or corn cobs, as a viable fuel source for farm and rural energy needs. The wise and effective use of corp residues could provide approximatley .4 quads of energy annually, or the equivalent of 15% of our natural gas usage in Illinois.

Livestock and Human Organic Wastes

Manures from livestock operations and wastes from municipal waste treatment plants are excellent materials for conversion to methane gas via anaerobic digestion. Prior to the availability of inexpensive natural gas and oil, many waste treatment plants produced methane for operation of plant machinery and the generation of electricity. A detailed assessment of livestock wastes characterized by quantity, type and economic and technical recovery approaches has not been conducted in Illinois. Generally, the greatest number of livestock are raised in confinement and feedlot operations, a practice which minimizes manure handling and contamination, and makes energy recovery more practical. There are several livestock confinement operations in Illinois which have installed anaerobic digestion systems for both stabilization of waste materials and the production of biogas for on-site energy use.

Volume III of the Illinois Water Quality Management Plan estimatess the 1974 total manure production from dairy and beef cattle, swine and poultry, at 3,091,451 tons, of which 61 percent is econmically recoverable.[7]

[7] Illinois Water Quality Management Plan, Volume III. Illinois Environmental Protection Agency.

Urban and Industrial Wastes

Illinois, as a heavily populated and industrialized state, produces a significant quantity of municipal and industrial combustible wastes. Estimates based on population statistics for Illinois calculate that over 6 million tons of processible municipal solid wastes are generated each year that could be recovered for energy production.[8] This is equivalent to 54 trillion Btu's of energy.

Municipal and industrial solid wastes are commonly transported to sanitary landfills for disposal. Disposal is a rapidly growing problem for our larger cities and small communities alike due to the increasing costs of landfilling practices and the environmental and cost consideration with the siting of new landfills. Municipal solid waste contains materials such as ferrous metals, aluminum, and glass which can be recovered, and up to 80 percent combustible organic materials which can be converted to energy. Although technologies for processing and converting solid wastes have historically experienced numerous operation problems, substantial technical improvements have allowed solid waste-to-energy systems to become a practical reality for both large and small waste generators. As a result, today there are about 125 small-scale and large-scale waste-to-energy plants in the planning, design, construction and operating stages in the U.S. capable of processing 133,000 tons of refuse per day. Several Illinois communities, and industrial and institutional facilities, are contemplating energy recovery technologies from the refuse they generate.

[8] A Study of Municipal Waste Alternatives, Including Resource Recovery for the State of Illinois Division of Land Pollution Control. IEPA. Franklin and Assoc. 1981.

Special Energy Crops

There are a number of plant species which are excellent sources of biomass to be converted to energy and fuels. These include woody plants, annual grasses, and aquatic plants and algae. In Illinois, research is underway on the production of fast growing specialized tree species which can be grown on marginal acreage. Woody biomass energy production by short rotation intensive farming techniques can produce between 4-8 dry tons of biomass per acre per year. Hybrid poplars, black locust, sycamore, autumn olive, and alder are tree species under investigation in Illinois. Several of these species are nitrogen fixing plants, and can improve the soil characteristics of the marginal lands where they are grown. Woody biomass energy farming may become an answer to plant growth on marginal non-agricultural land in Illinois. It is estimated that three quarters of a million acres of marginal lands are available in southern Illinois alone, in addition to marginal acreage in the rest of the state.[9] Over 158,000 acres of strip-mined and surface disturbed land are also candidates for woody biomass production in Illinois.

Several herbaceous plant species are under investigation from commercial adoption as agricultural crops in Illinois. One such plant, sweet sorghum, produces sugars in its stalk and starch in its grain that can be converted to ethanol. Another alcohol feedstock crop with development potential is the Jerusalem artichoke, which produces tubers with a high starch content.

[9] Department of Forestry, School of Agriculture, University of Illinois, Urbana, Illinois.

There are also a number of grasses such as sudan grass and kenaf, which produce a large quantity of biomass per acre. Several oil and hydrocarbon bearing crops are also being researched that can be processed into diesel fuel and petroleum substitutes. The widespread commercial adoption of specialized biomass crops in Illinois to produce energy and fuels is not likely in the near future without further research and development.

Biomass to Energy Conversion Process

Biomass cannot be used for energy until it can be converted into a usable fuel at a cost which is competitive with conventional fuels. The conversion techniques range from relatively simple to quite complex. The ultimate availability of all biomass conversion technologies is restricted by the amount of feedstock that is economically available for energy conversion. Basically, there are two types of biomass energy (bioenergy) conversion processes:

-- thermochemical conversion, and
-- biological conversion.

Biological conversion (bioconversion) is a chemical reaction caused by treating biomass with enzymes, fungi or micro-organisms. The conversion processes produce either liquid or gaseous fuels. Two processes are used today:

-- anaerobic digestion, and
-- fermentation.

Thermochemical conversion processes use heat (sometimes in the absence of air) to produce chemical reactions in biomass which provide energy in the form of steam, heat, or gas and liquids. Examples of such conversions include:

-- direct combustion,

-- gasification,

-- pyrolysis, and

-- liquifaction.

Biological Conversion Processes:

Bioconversion is the biological degradation of complex organic compounds into simple compounds, with subsequent collection and storage of the desirable products of the process. Bioconversion results in the production of liquid or gaseous fuels from solids, wastes or otherwise underutilized resources. Potential organic pollutants are very often suitable feedstocks for producing energy via bioconversion.

Two major biological pathways exist for converting biomass to fuel: anaerobic digestion and fermentation. The specific physical and chemical characteristics of a particular biomass resource determines which bioconversion process is most appropriate. A discussion of the two processes and some appropriate feedstocks is presented in the following sections.

-Anaerobic Digestion

Anaerobic Digestion is the process by which carbonaceous material is biologically decomposed in the absence of air to produce "biogas", a mixture primarily composed of methane, carbon dioxide and some trace gases as impurities. Optimal temperature ranges are maintained to allow rapid decomposition and maximum methane gas generation. A wide variety of biomass materials are suitable feedstocks for the process, although organic materials with high moisture contents are most commonly used. Table 1 outlines the salient characteristics of various anaerobic digestion substrates.

The anaerobic digestion process can be divided into three distinct steps: solubilization, acid formation and methane production.[10] These steps are illustrated in Figure 1.

1. Solubilization: The complex organic compounds present in the raw feedstock are mostly insoluble. Enzymes secreted by anaerobic bacteria dissolve or liquify the organic solids into complex soluble organic compounds. Depending upon the composition of the feedstock and presence of specific enzymes, varying amounts of residual organic compounds will be present in the digester effluent.

2. Acids Formation: Following solubilization, a general class of microorganisms known as the volatile acid formers utilize the soluble organic compounds to produce short-chain volatile acids such as propionic, acetic and butyric acids. Carbon dioxide is a by-product of this process. This step can proceed over a wider temperature range than the solubilization and methane production steps.

[10] Operation of Wastewater Treatment Plants, Water Pollution Control Federation, Lancaster Press, 1976.

Table 1: Characteristics of Various Substrates for Anaerobic Digestion

Feedstock	Availability	Suitability for Digestion	Special Problems
Animal wastes			
Dairy................	small to medium-sized farms, 30 to 150 head	Excellent	No major problems, some systems operating
Beef cattle.........	Feedlots, 1,000 to 100,000 cattle	Excellent	Rocks and grit in the feed required degritting, some systems operating
Swine...............	100 to 1,000 per farm	Excellent	Lincomycin in the swine feed will inhibit digestion--full-scale systems operating on university farms
Chicken.............	10,000 to 1 million per farm	Excellent	Degritting necessary, broiler operations need special design due to aged manure, tendency to sour
Turkey..............	30,000 to 500,000 per farm	Excellent	Bedding can be a problem, manure is generally aged, no commercial systems operating
Municipal Wastes			
Sewage..............	All towns and cities	Excellent	Usually too dilute for efficient net energy yield, vast experience
Solid wastes.........	All towns and cities	Organic material other than	Need separation facilities on the front end, commercial system in opera- tion, digests slowly
Crop Residues			
Wheat straw..........	Some cropland	Fair, perhaps better suited to direct combustion	Particle size reduction necessary, low digestibility, no commercial systems
Corn stover..........	Some cropland	Fair, perhaps better suited to direct combustion	No commercial systems, no data available, particle size reduction necessary

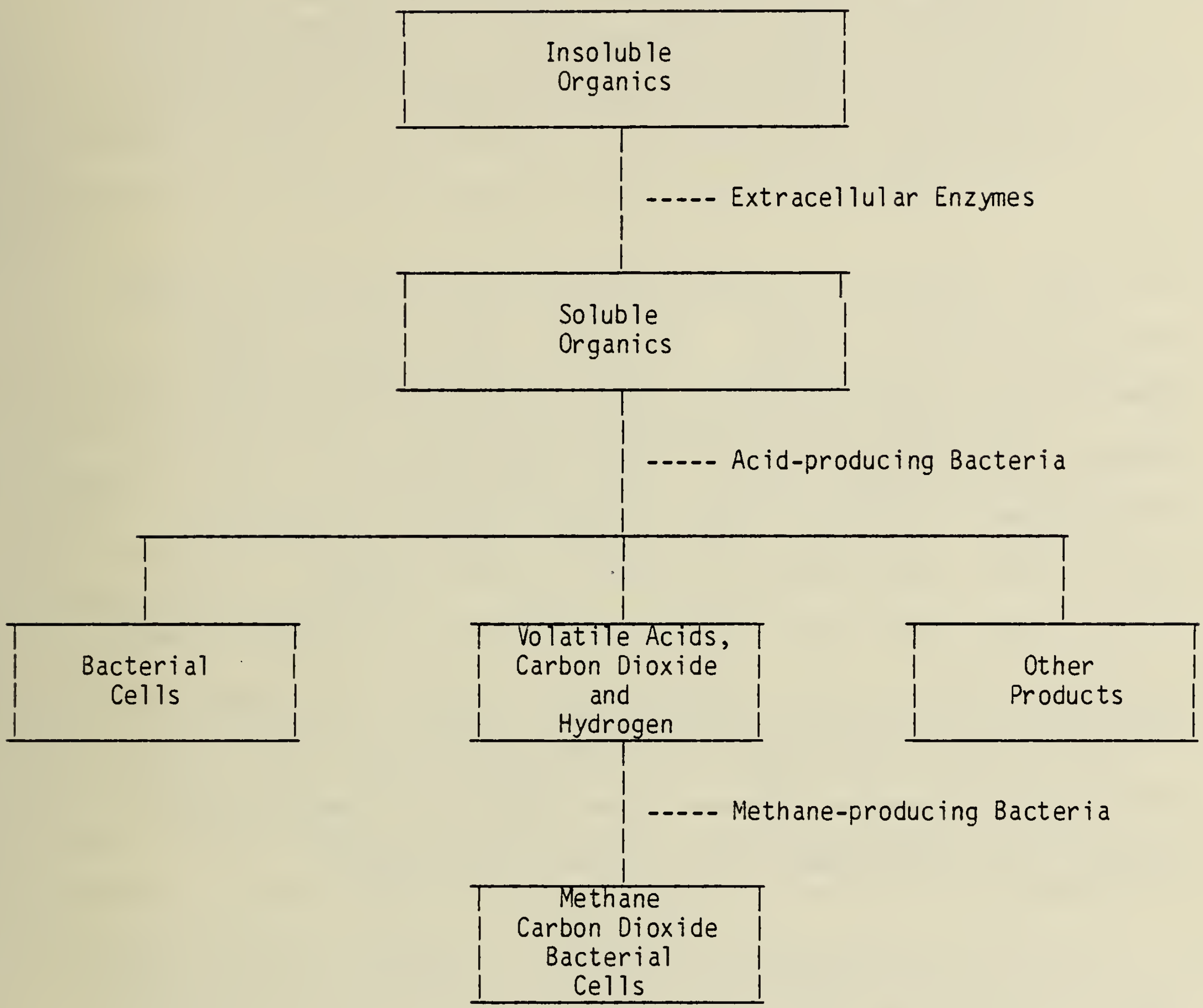
Table 1: Characteristics of Various Substrates for Anaerobic Digestion (continued)

Feedstock	Availability	Suitability for Digestion	Special Problems
Grasses			
Kentucky blue........	Individual home lawns	Good	Distribution of feedstock disperse, no commercial systems, digests slowly
Orchard grass........	Midwest	Fair	No commercial systems, no data on sustainability of yields
Alfalfa.............	Throughout the United States	Good	No data
Aquatic plants			
Water hyacinth.......	Southern climates very high reproduction rates	Very good	No commercial operations, need pre-grinding
Algae................	Warm or controlled climates	Excellent	
Ocean kelp...........	West coast, Pacific Ocean, large-scale kelp farms	Excellent	Full-scale operations not proven, no present value for effluent
Various woods.........	Total United States	Poor, better for direct combustion or pyrolysis	Will not digest
Kraft paper..........	Limited	Excellent, need to evaluate recycle potential and other conversion processes	Premixing watering necessary

Source: Office of Technology Assessment, U.S. Congress.

FIGURE 1

The Stages of Anaerobic Digestion



Source: Journal of the Water Pollution Control Association

3. Methane Production: This portion of the digestion process is the slowest and most environment-sensitive of the three stages. The methanogenic bacteria grow much slower than the others and require more time to recover from system shocks. The methanogens utilize the volatile acids formed in the second stage to produce methane and carbon dioxide.

The two major approaches to anaerobic digestion are the batch-type digester and the continuous-feed reactor. In the batch-type system the digester is loaded with the feedstock materials, then sealed and allowed to react until completed. This approach results in uneven gas production with very little methane produced initially, a surge in biogas production during active digestion then a gradual tapering of the rate of gas formation. In the continuous-feed system organic material is added to a flow-through digester at frequent intervals, with a retention time calculated to allow the reactions to reach completion before exiting the reactor vessel. Biogas yield tends to be fairly constant, as some organic material is always actively digesting at any given moment in the continous-feed digester.

The plug flow or the continuous feed systems may be operated in the mesophilic (80°-100°F) or the thermophilic (110°-140°F) temperature ranges. The rate of gas formation increases with increasing temperature and retention times drop accordingly. However, total amount of biogas produced does not change when all other parameters are equal. Due to the added costs of maintaining digester temperatures in the thermophilic range, almost all anaerobic digestion systems presently in operation operate in the mesophilic temperature range.

The biogas produced from anaerobic digestion primarily consists of methane (typically 60%) and carbon dioxide.[11] Trace impurities are usually hydrogen sulfide, mercaptans, and hydrogen. The Btu content of the raw biogas varies according to the gas composition, with a representative energy content of 500-600 Btu/SCF. Gas cleanup may be accomplished by scrubbing the CO_2 and H_2S, with a resultant boost in the Btu content of the fuel.

The relatively low energy content and variable production rate of biogas results in the most practical use on-site for a variety of fuel uses such as boiler fuel, electricity generation and stationary power applications. Biogas is also an acceptable vehicle fuel in suitably modified engines, but the relatively low energy density of the gas makes compression, storage and transport less attractive.

The digester effluent is usually a more desirable fertilizer product than the raw influent. The anaerobic digestion process renders the volatile organic compounds in the feedstock more stable, and odors due to ammonia formation are absent from the digester effluent. Compounds that are not degradable by the bacteria in the digester, such as lignins and hemicelluloses, can be incorporated as fertilizer with the rest of the effluent with benefits to the soil's structure.

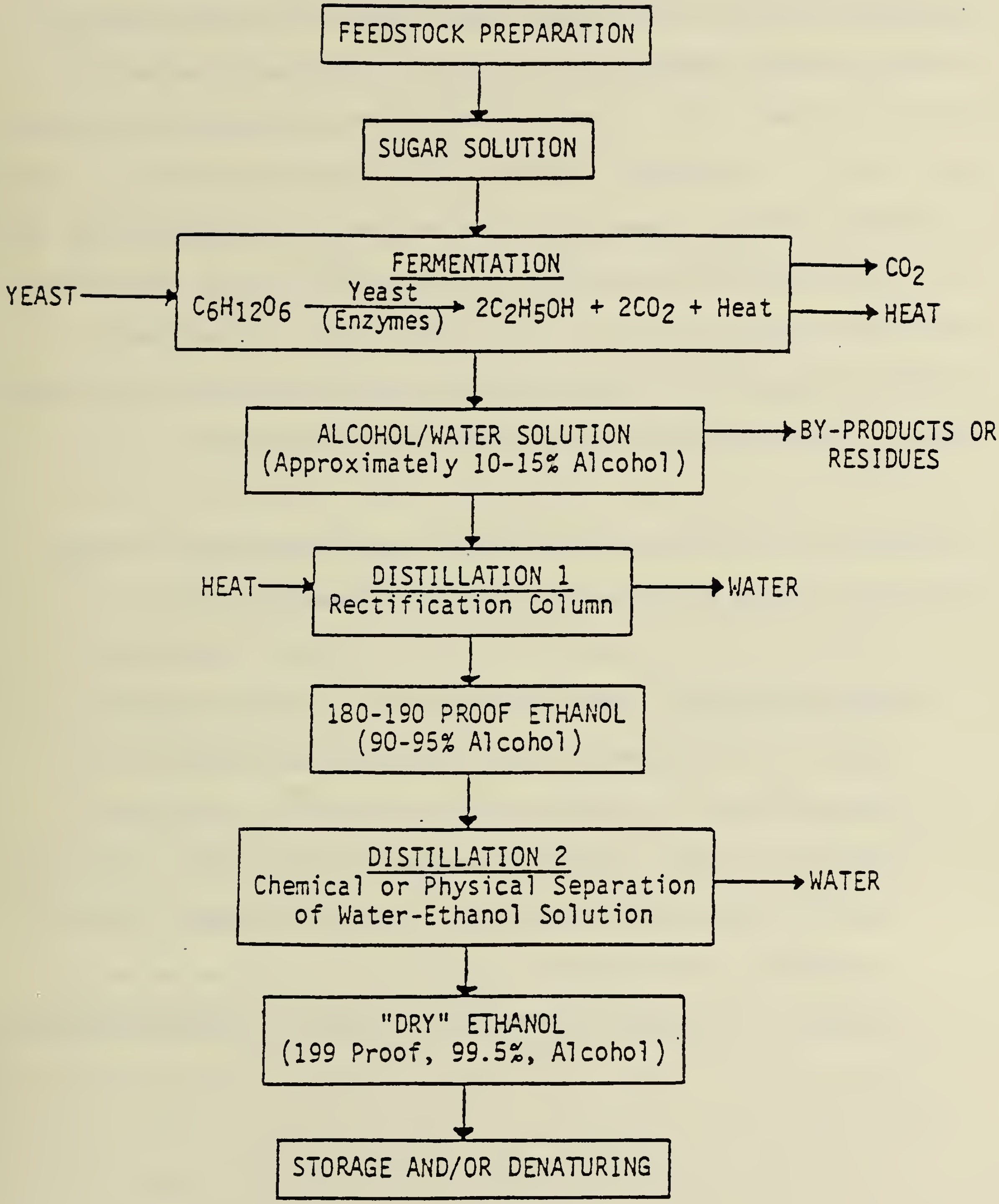
[11] Biomass: Applications, Technology and Production; N.P. Cheremisinoff, P.N. Cheremisinoff and F. Ellrbusch, 1980.

The future of anaerobic digestion is one of process application rather than technological advances. The process is often directly applicable in solving waste disposal or other environmental problems, if not strictly from an energy resource standpoint. In this case, energy and environmental considerations coincide. As energy prices continue to rise, more organic waste streams and other suitable feedstocks will be cost-effectively converted by anaerobic digestion to low-Btu gas. Many substances now presenting a "waste disposal" problem due to their high organic content may be converted to a net energy gain through the application of the anaerobic digestion process. Although the process is a relatively simple technology, it is not yet fully understood and few commercial systems are presently operating. However, anaerobic digestion is widely applicable to municipal, industrial and agricultural operations, and more rapid implementation of this technology is anticipated as energy and environmental concerns receive greater attention.

- Fermentation:

Fermentation is a process by which simple carbohydrates are converted to carbon dioxide and alcohol (usually ethanol) through the metabolic activities of specific fungi or bacteria in a limited-oxygen environment. Although a relatively wide range of biomass resources are applicable to this process, all must be converted to their base sugar constituents before they are utilizable for fermentation. The general process is outlined in Figure 2.

Figure 2



Fermentation Process

The feedstocks for alcohol production may be divided into three major categories: sugar crops (sweet sorghum, sugar beets, wastes from candy factories, etc.), starch crops (grains, potatoes, food processing wastes, etc.), and cellulose (wood, paper, grassses, etcc.). The most commonly used feedstock in the U. S. at present is grain (corn); significant amounts of alcohol are produced from sugar crops. Cellulose conversion, while technically feasible, is not yet economically attractive enough to encourage its use as a feedstock for alcohol production from fermentation. Either ethanol or butanol can be produced from these feedstocks, depending upon the organism used, although ethanol is by far the most common product of the two.

The production of alcohols via fermentation may be delineated into three major steps: saccharification, fermentation and distillation.

1. Saccharification: All feedstocks for the alcohol production process must be degraded to their base sugar constituents prior to fermentation. If a sugar crop is used, no prior conversion is necessary. Starch feedstocks require saccharification through the use of cooking and the application of specific enzymes. Cellulosic degradation into fermentable sugars usually requires one or more chemical or physical pretreatment steps prior to saccharification.

2. Fermentation: In the fermentation step, microorganisms (bacteria or yeasts) metabolize the sugars from the saccharification step to produce cell mass, alcohols and carbon dioxide. Proper fermentation is dependent upon the maintenance of environmental factors such as pH, temperature and feedstock sugar content.

3. Distillation: The "beer" exiting the fermenter typically ranges from 10% - 15% alcohol by weight. Concentration of the alcohol is accomplished via distillation, or heating the beer to a point below the boiling point of water but at or above the boiling point of the alcohol. The alcohol vapors are subsequently condensed in a cooling column and collected. Up to 95% ethanol (190 proof) may be obtained through simple distillation. Due to the formation of an azeotropic bond between the water and ethanol, production of anhydrous (water-free) ethanol requires chemical extraction (using benzene, ethyl acetate or propanol, for instance) or physical separation via the use of a molecular sieve apparatus or other absorptive material. Production of butanol from fermentation does not form the azeotropic bond as does ethanol and water. Therefore, only simple distillation is required to produce a relatively pure butanol product.

Unlike anaerobic digestion, major technological advances in producing alcohols may alter the actual process approach drastically. Recent process improvements have increased the efficiency of production, and significantly reduced the amount of energy required to produce fuel quality ethanol. Promising changes in the alcohol from fermentation process include:

- Vacuum distillation: Distillation in the presence of a slight vacuum occurs at a reduced temperature due to the lowering of the boiling point for the alcohol. Present research is investigating the advantages of vacuum distillation over atmospheric distillation in terms of energy savings, flexibility of fuel source for the distillation process, and simultaneous fermentation and distillation through the use of thermophilic microorganisms.

- Continuous fermentation: The introduction of the Wick continuous flow fermenter has sparked research into the device's applicability to various feed stock materials. Through the maintenance of very high cell population density in the fermenter and the thorough contact of the feedstock with the organisms, retention times in the reaction vessel may be reduced by up to 90% over the normal batch-type system.

- Cellulose conversion: Research is continuing in the area of converting cellulose resources into alcohol. Advantages of cellulosic materials as feedstocks are their widespread availability, low cost and few competing uses. This process has been proven technically feasible through the use of chemical and/or enzymatic hydrolysis of the cellulose molecule into its simple sugar constituents, but the economics of such a process at a commercial scale is uncertain under the present market conditions. Further research could result in the refinement or improvement of the process in economic terms.

The Future of Biological Conversion Technologies:

Anaerobic digestion and fermentation technologies are presently economically viable. With the exception of the research areas outlined in the fermentation section, the future of both technologies is likely to concentrate on resource applications rather than major technology advances. The most promising applications in the near future will likely be utilization of industrial, domestic and agricultural wastes and residues instead of utilizing agricultural crops, including the culture of special energy crops. These wastes and residues, as a group, represent the most cost-effective feedstocks for the process, a factor likely to be given great weight in resource allocation decisions. As energy prices and feedstock costs continue to rise, more underutilized resources ("wastes") will be examined as to their applicability to bioconversion techniques.

The application of bioconversion techniques to specialized energy crops may gain more widespread acceptance, particularly if the crop is a perennial that can be cultured on marginal agricultural lands. Promising crops under investigation include various grass species, Jerusalem artichokes, and rapid growing, rejuvenating tree species such as hybrid poplar, sycamore, cottonwood and others. These biomass resources may prove to be economic and environmentally sound feedstocks for one or more of the bioconversion technologies.

The future of the bioconversion techniques is promising in view of their ability to produce needed gaseous and liquid renewable fuels from domestically produced wastes and cultured biomass resources. These processes are gaining more widespread acceptance in the U.S. as other energy resources become increasingly expensive or unavailable.

Thermal Conversion Processes:

Direct Combustion

Direct combustion is the simplest and most developed biomass conversion process. It involves the conventional burning of biomass materials or solid waste in the presence of oxygen for use as a direct heat source. Combustion takes place in three processes:

a) evaporation of moisture content - heat is applied to evaporate moisture in the fuel.

b) distillation of burning volatile matter - heat is absorbed by the fuel, raising its temperature. Volatile hydrocarbons are released, mixed with oxygen and burned to generate heat.

c) combustion of fixed carbon - more heat is generated as the fixed carbons oxidize at higher temperatures and combustion is completed.

Initially these processes occur in sequence. As combustion progresses, the process takes place simultaneously and biomass sustains its own combustion. Excess air is normally supplied to achieve complete combustion. The important constitutents of biomass that influence the combustion process and design of firing equipment are: 1) moisture content, 2) volatile matter, 3) fixed carbon, and 4) ash.

Forest and agricultural residues and wastes can be burned to produce steam, electricity or heat. Direct combustion applications are found in the industrial, commercial, agricultural and residential sectors. These systems range from simple fireplaces, wood stoves and crop residue burners to large industrial boilers burning many tons of wood per hour. Boilers for industrial and utility applications are available in small packaged units or large units that can be erected on-site depending on the capacity of the plant.

There is considerable potential in Illinois for agricultural crop residues which can be utilized as an energy source. Large quantities of propane and natural gas are presently used for grain drying and heating farm houses. Several crop residue burners have been developed to burn crop residues to produce heat for grain drying. Large scale commercialization of these system has yet to take place.

Municipalities and industries produce large quantitites of refuse daily. Nearly 80% of this waste contains organic, combustible materials which can be burned to generate steam to produce electricity or to provide heating and cooling of industrial processes. Using solid waste for energy conversion has in recent years become more popular and a solution to waste disposal problems.

Water wall combustion systems are largely used to burn solid waste. They burn solid waste in a specially designed furnace, jacketed with water-filled tubes to recover heat as steam for direct use or conversion to electricity.

Waterwall combustion systems are classified according to the form of solid waste utilized:

1) unprocessed or as received (stoker firing)
2) shredded (semi-suspension firing)
3) RDF (suspension firing)

The first system (see Figure 3) often termed "mass" or "bulk" burning, and burns unprocessed or as received MSW on mechanical grates or stockers which move through the furnace. Non-combustible materials fall off at the end of the grate and are quenched in a pit of water, then conveyed to trucks for disposal or to a storage pit.

Shredding solid waste before combustion produces a more homogeneous and controllable fuel. "As received" MSW is coarsely shredded before being mechanically or pneumatically charged into the furnace and burned on a moving grate. This type of firing is called semi-suspension firing, because waste is ignited while it is falling through the furnace chamber, and combustion completes when it is resting on the grate.

Refuse derived fuel (RDF) is the organic, combustible portion of solid waste that has been separated from the non-combustible fraction through processes such as shredding, screening and air classifying (see Figure 4). Through processing, RDF containing 10 to 13 million BTUs per ton can be produced. RDF can also be densified to produce a uniform high mass density and volume density, easily storable and transportable fuel called densified RDF. These fuels are most suitable for direct combustion or for use as supplemental fuel in waterwall boilers designed to burn coal or other solid fuels.

Figure 3

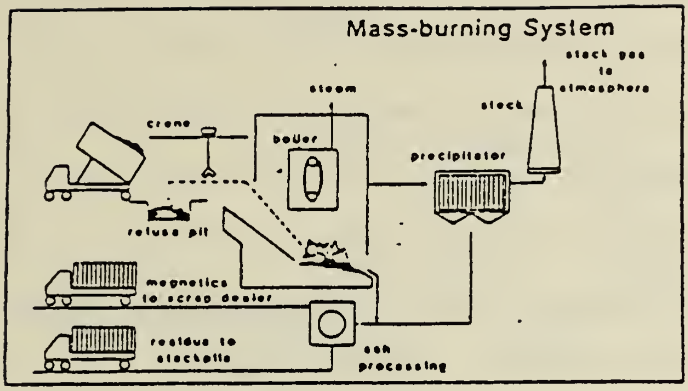
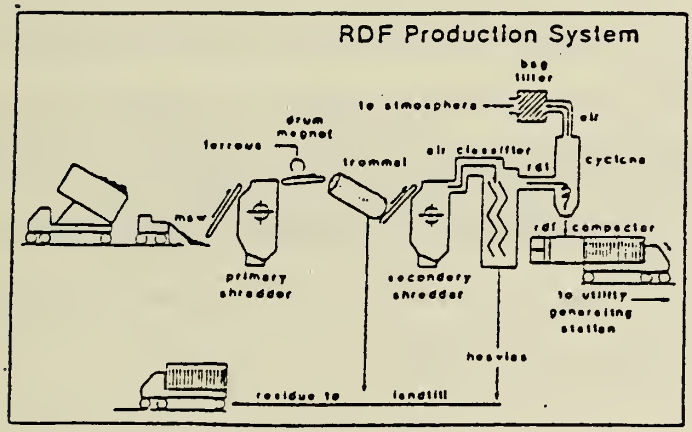


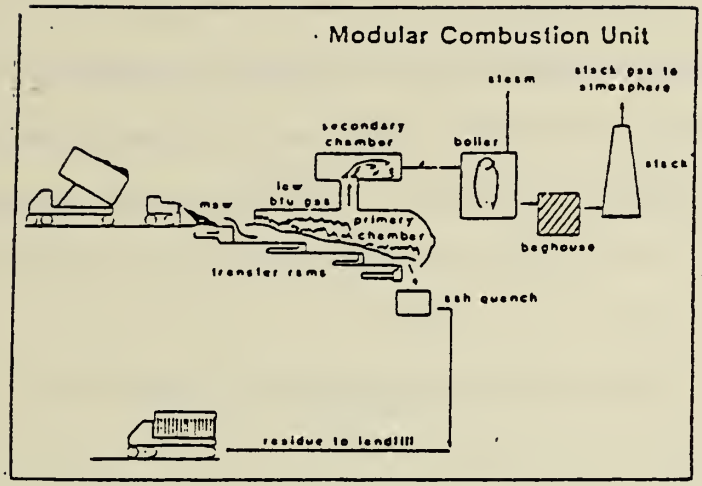
Figure 4



Source: "California Waste Energy Projects Learn from Others," by Neal Johnson, et al, Solid Waste Management Report, August, 1981.

Modular combustion systems are small heat recovery incinerators suitable for small waste producers such as small communities, institutions and industrial facilities. They burn waste materials in two controlled air chambers as shown in Figure 5. Solid waste is charged by a hydraulic ram feeding device into the primary chamber, at pre-set intervals controlled by temperature sensor or timer. Burners ignite the waste, the bulk of which burned in an oxygen starved atmosphere. Combustion gases at 1200°F to 1600°F from the primary chamber are channeled up into the secondary chamber, where combustion is completed with the addition of excess air. Auxiliary fuel burners are provided in both the chambers, for startup and temperature control. The hot gases of combustion in the secondary chamber at 1500°F to 1800°F are diverted through a boiler to produce steam, before leaving through the stack. Because combustion takes place with controlled quantity of air, it produces a low gas volume and velocity. Consequently, relatively clean effluent gases are produced, requiring no air pollution equipment. These units are shop fabricated and available as modules in capacities ranging from 5 to 50 TPD. Relatively low cost, sizing flexibility, compact design, low particulate emissions and minimum labor requirement of MCU systems, potentially offer a new tool to recover energy from refuse.

Figure 5



Source: "California Waste Energy Projects Learn from Others," by Neal Johnson, et al, Solid Waste Management Report, August, 1981.

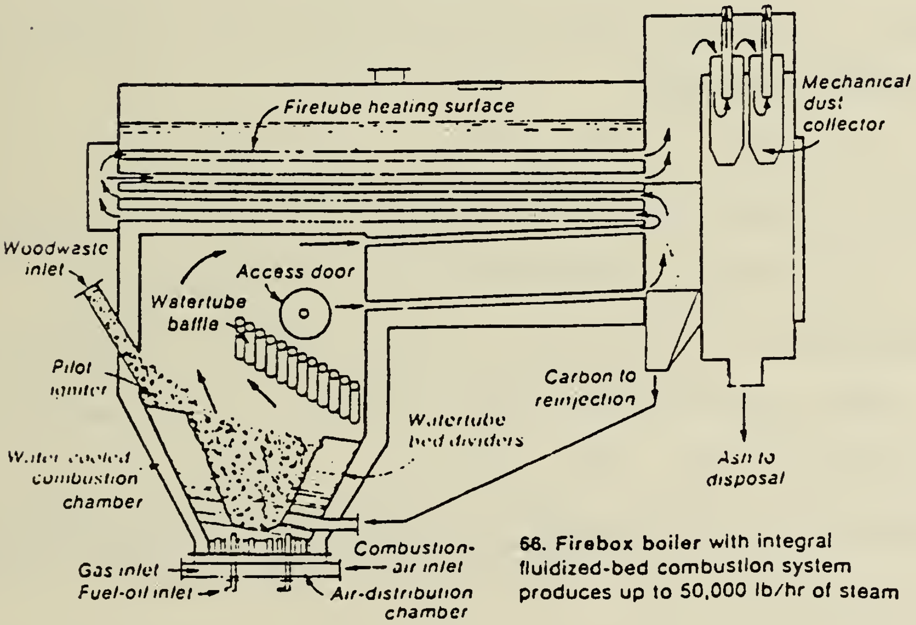
Fluidized-Bed Combustion

Fluidized-bed technology is a relatively new application in the field of solid waste combustion. The term "fluidized-bed" is derived from the unique use of particles such as sand or other granular material that are suspended ("fluidized") in the combustion chamber by a steady blast of air. This bed of suspended particles is heated to approximately 700°F (371°C), and combustible solids are fed into the combustion chamber. The excellent heat transfer properties of the mass of fluidized particles ensures rapid and total oxidation of fuel materials, resulting in increased combustion efficiencies and much reduced air pollution from burning solid wastes. The combustion process is self-sustaining as long as air and fuel supplies continue.

A fluidized-bed combustion chamber is basically a refractory-lined cylinder with the inlet air ports arranged in a distribution plate near the bottom of the chamber. The fluidized-bed materials are suspended above the distribution plate by a sustained stream of air entering through the air inlet ports, which also provides excess air for complete combustion. An air blower of sufficient capacity is required to maintain adequate air flow to the system. A complete fluidized-bed combustion system also includes fuel handling, gas clean-up and emission control equipment. These systems are capable of efficiently

burning non-uniform fuels such as wood, solid wastes, coal and others even if the fuel contains considerable non-combustibles such as dirt and stones. Fuel moisture contents of more than 15% by weight are entirely acceptable to a fluidized-bed combustion system. Figure 6 illustrates utilization of wood in an industrial boiler via fluidized-bed technology.

Figure 6



66. Firebox boiler with integral fluidized-bed combustion system produces up to 50,000 lb/hr of steam

Source: "Power from Wood," by Bob Schwleger, Power Magazine, February 1980.

Gasification

Gasification is a thermal conversion of biomass in the presence of a limited amount of air or oxygen. When organic material such as wood, municipal solid waste or crop residues are decomposed by heating the material in the presence of air, low Btu gas (with a representative heating value of 100 to 150 Btu/Scf) is produced. Gasification is a viable technology for producing an environmentally acceptable fuel for process applications and power generation.

Low Btu or air gasification technology is the simplest (commercially available) for most types of lower moisture biomass feedstocks. The versatility of low Btu gas is limited and its use is subjected to the following limitations:

- The low heating value of gas usually requires that it be consumed on or near the production site in a close coupled process.
- Substitution of low Btu gas for natural gas as a boiler fuel usually requires boiler derating and/or extensive retrofit modifications.
- The high nitrogen content of low Btu gas precludes its use as a synthesis gas for most chemical commodities which can be produced from synthesis gas.

A medium Btu (MBG) or oxygen gasification process requires use of oxygen for gasification which is very expensive to produce and requires an oxygen plant. However, medium Btu gas offers the following advantages over low Btu gas:

- Boiler derating is usually less severe when substituting MBG for natural gas than when substituting low Btu gas for natural gas.
- MBG can be transported moderate distances by pipeline at a reasonable cost.
- MBG is utilized for the synthesis of derived fuels and most chemical feedstocks and commodities which can be produced from synthesis gas.

In spite of the above advantages of MBtu gas, low Btu gasification (LBG) is often considered more attractive than medium Btu gasification because of the initial costs and technical problems connected with construction and operation of an oxygen plant for an MBG facility, which may cost as much as 40 to 45 percent of the total expenditure for a gasification facility.[12] The average thermal conversion efficiency of producing MBG is 75 percent; which is 10 to 15 percent higher than that of LBG.[13] This greater thermal efficiency of an MBG system is offset, however, by the lower capital cost associated with the LBG plant. Commercial biomass to MBG systems are still being developed, and are not generally available.

[12] "Near Term Potential of Wood as a Fuel" Prepared for U.S. DOE by the Mitre Corporation, 1979.

[13] Ibid.

Forest waste and waste from wood processing operations, agricultural residues, and every conceivable form of cellulose can be used to produce low Btu gas. Saw mills and lumber mills can use their waste to generate gas for use in natural gas kilns. These gasifiers can be retrofitted easily to natural gas or oil fired boilers producing process steam or electricity for industrial or utility applications. This eliminates the need to replace the entire system as required for conversion to direct combustion of solid fuels such as wood or coal. Retrofitting an existing gas or oil system with a biomass gasifier costs between $10 and $15 per pound of steam per hour.[14] A new gas or oil installation may cost two to three times as much.

Air gasification has the most immediate and widespread commercial potential in Illinois for gasification of agricultural crop residues. Illinois, being an agricultural state produces large quantities of crop residues. These crop residues can be gasified to produce a low Btu gas suitable for grain drying and space heating applications. Development of agricultural residue gasifiers could partially meet the energy needs of Illinois farms while reducing fuel costs and conserving large amounts of presently used non-renewable fuels such as propane and natural gas.

Types of Gasifiers

Air gasification has the most immediate commercial potential for use with industrial natural gas and oil fired boilers. Three main types of gasifiers have been developed:

[14] "Wood as an Alternate Energy Source", published by the Georgia Institute of Technology, Engineering Experiment Station, Atlanta, Georgia, 1979.

1) Updraft or fixed bed,

2) Downdraft, and

3) Fluidized bed.

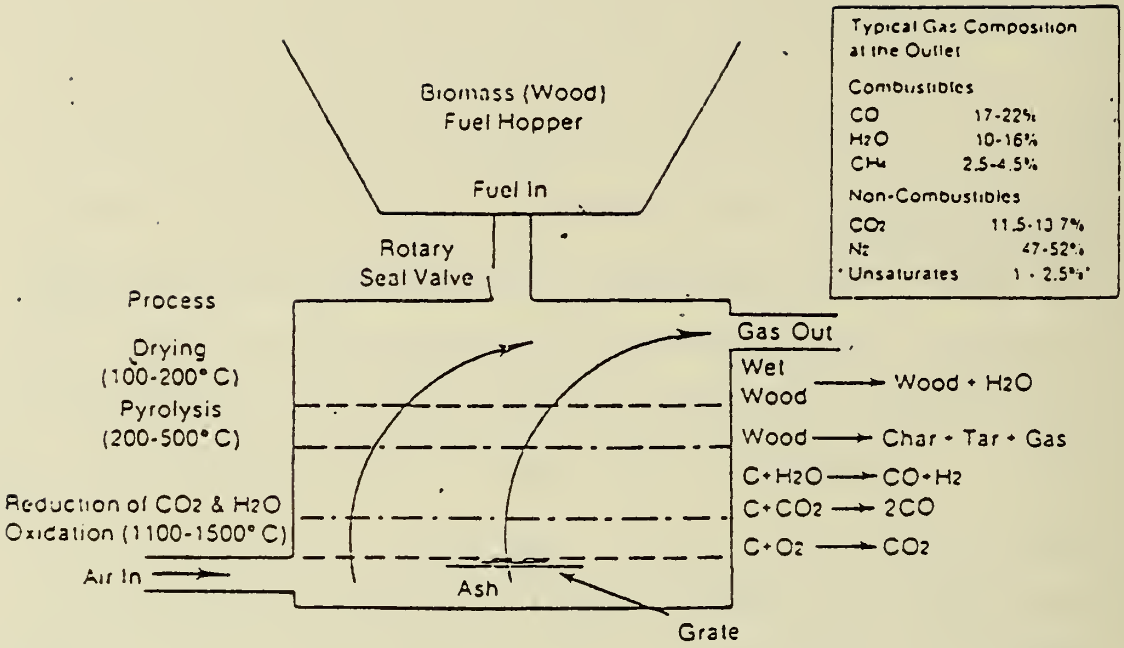
Updraft Gasifier

An updraft, fixed bed gasifier is a simple gasification technology (Figure 7). Biomass with a relatively high moisture content is fed into the top of the gasifier. Water vapor is driven off in the upper zone at temperatures of 100°C - 200°C. The dried material next undergoes destructive distillation. Temperatures required for this reaction are in the range of 200°C - 500°C. The reaction takes place in an oxygen free atmosphere resulting in the production of char (primarily carbon), tars and gases (the reduction of some CO_2 and H_2 and CO). In the final zone, oxygen entering the bottom of the gasifier oxidizes the char produced in the second zone with a resultant emission of CO_2.

Hence the major combustible products of this type of gasifier are CO, H_2 and some light hydrocarbons. Generally the gases in this raw form will have a heating value of 150 BTU/scf.

Tar formation early in the gasification process can produce a significant detrimental effect. However, combustion in a close coupled mode of the heated gas can cause tar combustion as well, with the added benefit of increased energy value.

Figure 7



General Diagram of Updraft Gasifier

Source: Decision Makers Guide to Wood Fuel for Small Industrial Energy Users, Solar Energy Research Institute.

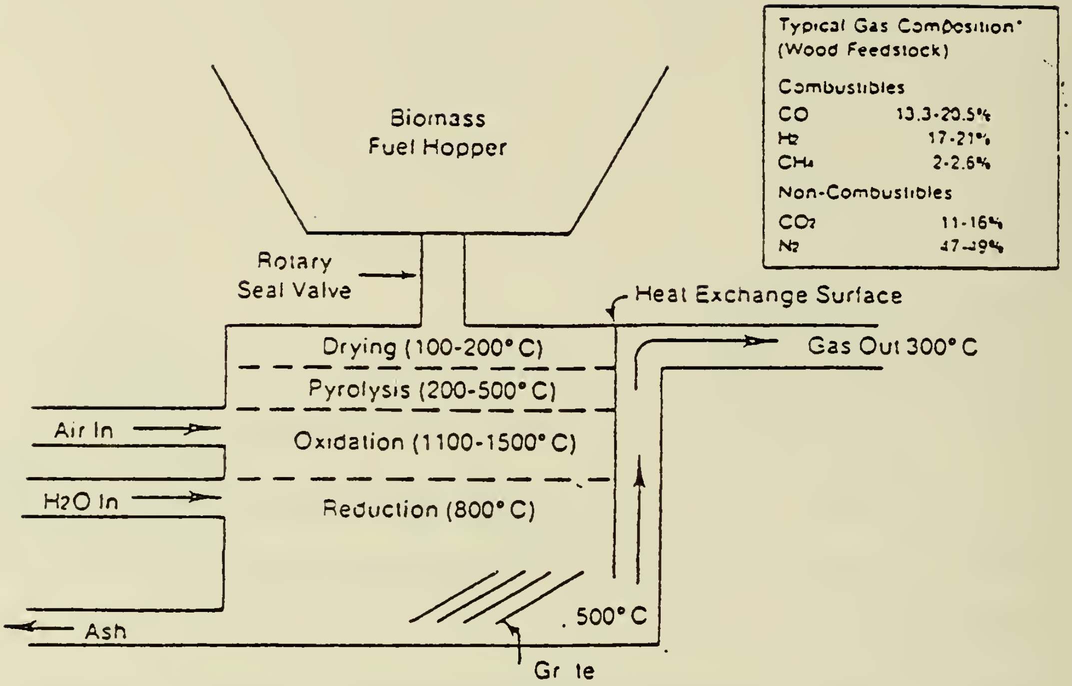
The utilization of gases from this system for engines of pipeline transport will necessitate cleaning, resulting in increased production costs as well as a reduction of energy balue to approximately 90 BTU/scf.

Downdraft Gasifier

Downdraft gasification, as the name implies, entails the forced introduction of air into the top of the gasifier chamber with exits provided in the bottom. This system produces much less tars than the updraft gasifier because all the tars and gases must pass through the hot oxidation zone prior to exiting. For this reason, downdraft gasifiers have been used to power both compression and spark-ignited engines for transportation use, and to provide a low-Btu substitute boiler fuel. A general diagram of a downdraft gasifier is illustrated in Figure 8.

The downdraft gasification process is diagramed in Figure 8. The incoming biomass feedstock passes through a drying zone and enters a pyrolysis zone where gases, tars and char are produced. These pyrolysis products contact incoming air and are oxidized at high temperatures. The gases and char remaining then pass through a cooler reduction zone, where most of the tars are degraded into gases. Thus, very little tars or other gas contaminants are produced by the downdraft gasification system compared to other gasifier designs.

Figure 8



General Diagram of Downdraft Gasifier

Source: Decision Makers Guide to Wood Fuel for Small Industrial Energy Users, Solar Energy Research Institute.

Downdraft gasifiers hold much promise for small- to medium-scale applications. The major constraint on the adoption of the technology in industrial and other large-scale applications is the upper limit experienced in the total area of the gasifier grate, which in turn determines the throughput and capacity rating of the gasifier. Large grates provide an uneven flow of gas which promotes bed instability and allows the char bed to collapse. Therefore, the use of downdraft gasifiers in larger industrial boiler settings is limited.

Fluidized Bed Gasifiers

A fluidized bed gasifier uses a steady blast of air into the bottom of the reactor to provide combustion air and to maintain a bed of sand or other granular material in suspension. This turbulent mass of particles is heated prior to the introduction of the material to be gasified. Once the fluidized bed reaches operating temperature biomass particles are introduced and contact the hot sand, where rapid pyrolysis occurs. The gas producing reactions occur very rapidly due to the excellent heat transfer characteristics of the fluidized bed, allowing very short retention times compared to other gasification technologies. Thus, a much greater volume of biomass may be gasified in a given amount of time using the fluidized bed technology. In addition, a valuable charcoal by-product can be obtained from the fluidized bed gasification technique.

Economics of Gasification

Cost data on gasification systems are largely site-specific. Since few of these units have been put into industrial operation to date, there are no firmly established data on capital investment and operating costs. The price of LBG produced in small installations such as 1.9 x 10^9 Btu/day facility 170 oven dry tons/day (ODT/D) would be relatively high compared to that produced in large plants (850 ODT/D). The price calculated for 170 ODT/D low Btu gasification plant was $3.80/MMBtu and for 850 ODT/D facility it was $1.70/MMBtu. Wood fuel cost was assumed to be $1.0/MMBtu in both cases.[15]

There are currently about half a dozen gasifier manufacturers in United States who manufacture units which utilize biomass. Most of these systems are designed for wood wastes and have a heat output ranging from 60,000 to 50 million Btu/hr. Several systems are now commercially available on a limited basis, while a number of experimental prototype systems have been designed and are under testing. Development of efficient and cost effective gasifiers, coupled with proper crop residue collection and handling systems may allow widespread use in the agricultural sector, specifically for grain drying and space heating. With continued development, it appears that gasification will be a viable technology in the switch to biomass energy utilization.

[15] Ibid.

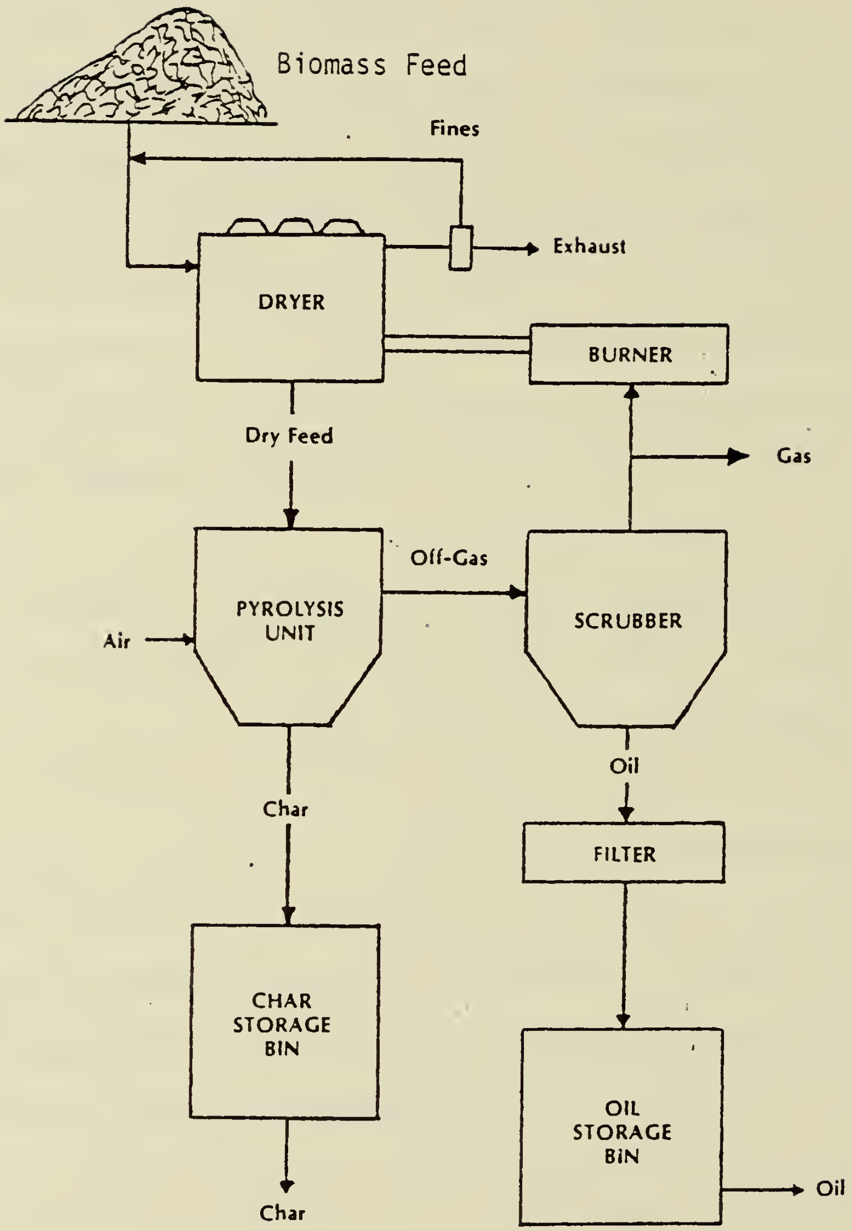
Pyrolysis

Pyrolysis is a lesser known bio conversion process. Pyrolysis is the destructive distillation (thermal breakdown) of biomass using mainly heat but in the absence of oxygen and at a lower temperature than is required for gasification. In practice, however, a small amount of air is introduced so that a small amount of the feed material (less than 5%) is burned to supply the necessary heat for decomposition of the remaining material. The products of pyrolysis are char, pyrolytic oil, a water phase containing organic compounds, and a noncondensed gas. (See figure 9). Pyrolysis offers a non-polluting method of converting a variety of biomass waste materials, such as agricultural wastes and wood residues, paper mill wastes and municipal solid wastes to clean burning fuels. A commonly known application of pyrolysis is the commercial production of charcoal from wood.

The pyrolysis reaction is initiated by an external heat source and maintained in a self sustaining mode by the careful control of air. Pyrolysis is generally conducted in the range of 1000°F to 1800°F.[16] Higher temperatures maximize gas production, while lower temperature minimize gas production and maximize pyrolysis liquid and solid (char) production.

[16] "Wood As An Alternate Energy Source", Georgia Institute of Technology, 1979.

Figure 9



Biomass Pyrolysis System

Adapted from: Wood an Alternate Energy Resource, Georgia Institute of Technology, September, 1979.

The principle product of pyrolysis is char, which is mainly carbon, and some ash from the original feed material. Char has a heating value of 12,000 to 13,000 Btu per pound and can be used as a fuel similar to coal.[17] The char can be used to produce charcoal briquettes for heating and for the production of activated carbon used for the removal of pollutants from waste and gaseous systems.

Pyrolysis oil is a complex mixture of organic compound different from petroleum oils, and is low in sulfur, nitrogen and ash. It has a heating value between 10,000 to 12,000 Btu's per pound, is suitable for boiler fuel, and burns by itself or in combination with #6 fuel oil.[18]

Pyrolysis gas, in a noncondensed form, is a mixture of combustible gases, an oil mist, and water vapor. It has a heating value of around 150 Btu/scf. The gas must be utilized at the site itself. It supports combustion and clean burning. Pyrolysis gas is a potential fuel for internal combustion engines.

On a dry basis of input load, approximately 65% to 70% of the energy content is contained in the char and oil which are storable and transportable fuel. Less than 5% is used to sustain the pyrolysis reaction in the process. The remainder of the energy is in the non-condensed gas.

[17] Ibid.

[18] Ibid.

Pyrolysis systems using wood wastes and solid waste have been under development for some time, but no pyrolysis system has left the pilot plant or development stage. Pyrolysis is a possible candidate for commercialization within the next decade as a source of usable fuels.

Considerations and Conclusion

The utilization of biomass for conversion to usable forms of energy or chemical feedstocks is highly dependent upon a variety of site-specific factors. While biomass is a significant energy source in terms of overall resource potential, logistical and economic factors may limit its use to small or medium scale applications. Generically, biomass can be characterized as a medium Btu fuel, low in density, bulky, varying in moisture content, and seasonally available. Thus collection, transportation, storage and processing costs are integral to the overall economics of converting biomass into energy. To illustrate this point, the underutilized Illinois crop residues available for energy use amounts to .4 quads annually. However, logistical considerations warrant that corn stover would not be a practical fuel to power a large electrical generation facility due to the extreme quantities needed and the large collection area necessary to accomplish this feat. However, small-scale or centralized applications, such as on-farm direct combustion or gasification may be a potential means for the agricultural community to approach energy self-sufficiency (i.e., grain drying, space heating).

The success of the fuel ethyl alcohol industry is based on an extensive, well established grain handling and transportation system that allows the marketing of grain for alcohol production through an identical network established for processing food products.

The use of biomass for energy requires a careful evaluation of its availability within a given area where it can be economically converted to energy, and matching this resource base to a potential end-user and appropriate conversion technology. Thus the quality and quantity of a particular biomass source, transportation, handling and processing costs, and the type of conversion technology and energy form desired, are all integral to the economic viability of energy generation from biomass. Where these conditions can be suitably addressed, biomass (in its many forms) can be a viable renewable option to meet the energy demands of many economic sectors of the state.

Glossary of Terms

Biomass: Biomass is organic material such as trees, crops, manure, and algae produced as a product or by-product of photosynthesis.

BTU: British Thermal Unit. The amount of heat required to raise the temperature of pound of water by one degree Fahrenheit.

High-BTU, (HBTU) energy content equivalent to 900-1000 BTUs per cubic foot

Medium-Btu, (MBTU) energy content equivalent to 300-500 BTUs per cubic foot

Low-BTU, (LBTU) energy content equivalent to 100-200 BTUs per cubic foot.

Butanol: ($C_4H_{10}O$) butyl alcohol

Carbonaceous Material: Any substance composed primarily of the element carbon (i.e., grasses, coal, wood, etc.).

Combustion: The rapid chemical combination of oxygen and carbonaceous material: carbon dioxide and water are formed and heat is released.

Distillation: The process of separating the components of a mixture by differences in boiling point; a vapor is formed from the solution by heating the liquid in a vessel and successively collecting and condensing the vapors into liquids.

Enzyme: A type of catalytic protein produced by living organisms; enzymes mediate and promote biochemical processes without themselves being altered or destroyed.

Ethanol: (C_2H_6O) ethyl alcohol.

Fermentation: The microbiologically mediated enzymatic transformation of organic substances, especially carbohydrates, generally accompanied by the evolution of a gas.

Fluidized Bed Combustion: A thermal combustion process where combustible materials are fed into a hot, finely divided inert material (or bed) which is in a turbulent or "fluidized" state due to the injection of air in the combustion chamber. This process allows more rapid and complete combustion.

Gasification: Is a thermal conversion of biomass in the presence of a limited amount of air, oxygen or hydrogen to produce a gaseous fuel.

Hydrolysis: The decomposition or alteration of polymeric substance by chemically adding a water molecule to the monomeric unit at the point of bonding.

Incineration: The combustion of refuse or other biomass to produce steam.

Mesophilic: Having optimum operating rate between 80°-100°F (27F° - 38°C).

Methane: A colorless, odorless, flexible gas produced by the breakdown of organic material, that can be used as a fuel.

Methanogenic: Microorganisms that produce methane gas from organic substrates.

Pilot Plant: A small-scale industrial plant, constructed to provide process testing and operating experience before construction of a full-scale commercial plant.

Pyrolysis: Thermal decomposition of organic materials in the absence of oxygen to produce gaseous, liquid and solid fuels.

RDF: Refuse derived fuel. The organic, combustible portion of solid waste which is separated from the non-combustible portion by shredding and mechanical separation.

SNG: Synthetic natural gas, also known as substitute natural gas.

Saccharification: The hydrolysis of a complex carbohydrate into a simpler soluble fermentable sugar, such as glucose or maltose.

Solid Waste: Any underutilized or waste solid, organic material from which energy can be extracted, such as municipal refuse.

Solubilization: The liquefaction of complex organic solids into complex soluble organic compounds.

Thermophilic: Having optimum operating rate between 110°-140°F (43° - 60°C).

ILLINOIS
HYDROPOWER RESOURCE SUMMARY
AND TECHNOLOGY ASSESSMENT

INTRODUCTION

Interest in the development of small-scale hydroelectric power has significantly increased in recent years. A number of states, including the State of Illinois, have initiated studies to assess the potential for increased small-scale hydroelectric generation.

Currently, hydropower accounts for less than one percent of the State's total electric generating capacity. Whether hydropower becomes an important resource for the State depends on future energy demand and the extent to which hydropower can help meet that demand. The physical potential for hydropower development and the potential for its economical development are very different. Historically, the flat topography of Illinois and the availability of alternate energy sources have limited hydropower development. However, recent increases in the costs of fossil and nuclear fuels have created new interest in the State's hydropower resource, and it appears that small-scale facilities, which once produced competitively-price electricity at a number of sites in Illinois, potentially can do so again.

Hydropower was the predominant source of power in Illinois in the late eighteenth and early nineteenth centuries. By 1790, the water mill had replaced the animal-powered mill as the most efficient and economical milling technology in Illinois. However, in the 1820's, with the advent of steam mills and the availability of coal, the share of Illinois' total power capacity accounted for by hydropower began to decrease. In 1882, the development of

methods to generate hydroelectricity stimulated additional development of Illinois' hydro resources, but centralized coal-fired, steam-electric plants were being developed simultaneously. By the early 1900's, hydropower could compete only marginally with coal as a source of power in Illinois. Although the total hydroelectric generating capacity in Illinois increased from 35 megawatts (MW) during 1911 and 1912 to 48 MW in 1953, it has since decreased.[1]

Hydroelectric power currently is generated at six sites in Illinois (Table 1) and accounts for only 33 MW of electric generating capacity, or 0.11% of the total 29,197 MW of electric generating capacity in Illinois (Table 2). Comparatively, hydropower accounts for 3% of the total electric generating capacity in the six states of Federal Region V (Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin), and 13% of the total electric generating capacity of the U.S. (as of April 1979). Thus, hydropower is a less important power source in Illinois than in Region V and in the nation as a whole. While hydropower's share currently is relatively small compared to Illinois' total generating capacity, its potential to provide an increased share of future capacity is encouraging.

[1] Federal Power Commission. 1953. Hydroelectric power resources of the United States, developed and undeveloped. Federal Power Commission, Bureau of Power, Washington, DC.

Table 1. Currently operating hydroelectric generating facilities in Illinois (COE 1979a and Shanks 1979).

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Usable Feet)	Maximum Storage (1,000 Acre Feet)	Existing[a] Capacity (MW)
Rock Island	Sylvan Slough	Moline Generating Station Dam	Iowa-Illinois Gas and Elec.	49,137	9	2	3.6
LaSalle	Illinois	Marseilles	COE (IL Power Co.)	5,065	14	0	2.3
Lee	Rock	Dixon	Commonwealth Edison Co.	5,079	9	6	4.0
LaSalle	Fox	Dayton Dam	No. Counties Hydro Elec. Co.	1,611	28	1	4.0
Winnebago	Rock	Rockton	S. Beloit Water, Gas & Elec. Co.	1,566	15	0	1.1
Will	Chicago Sanitary and Ship Canal	Lockport Pool	Metropolitan Sanitary District of Greater Chicago	507	38	0	17.0
Total existing hydroelectric generating capacity in Illinois							33.0

[a]Capacity data obtained from Shanks (1979).

Table 2. Electric generating capacity in Illinois, Federal Region V, and the US (Shanks 1979).

	Illinois (MW)	%	Region V (MW)	%	United States (MW)	%
Nuclear	5,717	20	13,264	12	53,604	9
Hydro	33	0.11	3,058	3	73,936	13
Oil	6,362	22	17,465	16	151,317	26
Coal	16,750	57	75,537	68	228,889	39
Gas	139	0	1,562	1	74,892	13
Unknown	197	1	817	1	1,587	0
Other	0	0	184	0	3,680	0
Total	29,197	100	111,880	100	587,873	100

Recent studies indicate that hydroelectric power production in Illinois can be increased by the development of several additional small-scale sites.[2]

HYDROPOWER RESOURCE ASSESSMENT

Two inventories of the potential for hydropower development in Illinois have been completed: (1) the U.S. Army Corps of Engineers (USCOE) Preliminary Inventory of Hydropower Resources, 2) the Institute of Natural Resources Inventory of Potential Small-Scale Hydropower Projects in Illinois).

[2] U.S. Corps of Engineers. 1979. Preliminary inventory of hydropower resources, national hydroelectric power resources study volume 4, Lake Central region. U.S. Department of the Army, Institute for Water Resources and Hydrologic Engineering Center, Ft. Belvoir, VA, variously paged.

U.S. Corps of Engineers, North Central Division. 1980. Main reliability council national hydroelectric power study. Draft. Department of the Army, Chicago, IL, variously paged, 120 pp, plus appendices.

WAPORA, Inc. 1980. Phase I report, inventory of potential small-scale hydropower sites in Illinois and selection of projects exhibiting potential for development. Chicago, IL, 29 pp, plus appendices.

WAPORA, Inc. 1980. Phase II report, preliminary investigation of small--scale hydropower potential at five sites in Illinois. Chicago, IL, 113 pp, plus appendices.

The COE inventory lists sites with and without dams that have a potential generating capacity of at least 50 kilowatts. The USCOE initially identified 303 sites in Illinois, including sites that are presently generating power.[3] Dams exist at only 57 of these listed sites. Construction of hydropower facilities at the sites without dams would be extremely expensive and would pose significant environmental problems. Sites with very small capacities also tend to have very high construction costs per kilowatt of capacity. Thus, although the total potential at the 303 sites was estimated to be approximately 1,121 MW, the potential capacity at sites that could be developed economically is significantly lower.

The preliminary inventory, however, does not include all sites. Any site with a potential generating capcity of less than 50 kilowatts (kw) was omitted. Generalized cost estimates for each site were compared with regional power values, and those sites that appeared infeasible were eliminated.

[3] U.S. Corps of Engineers, 1979a. Preliminary inventory of hydropower resources, national hydroelectric power resources study, volume 4, Lake Central region. U.S. Department of the Army, Institute for Water Resources and Hydrologic Engineering Center, Ft. Belvoir, VA, variously paged.

In addition, some sites were omitted inadvertently. In a study commissioned to WAPORA Inc. by INR, 57 additional sites (with existing dams) were documented. Hence a total of 114 sites with dams have been identified. (Figure 1 and Appendix A).

Furthermore, the potential capacity listed for each site in the COE Preliminary Inventory probably overestimates slightly the actual capacity available. The COE made conservative assumptions and calculations during the screening process to avoid omitting any potentially developable sites. These assumptions and conclusions include:

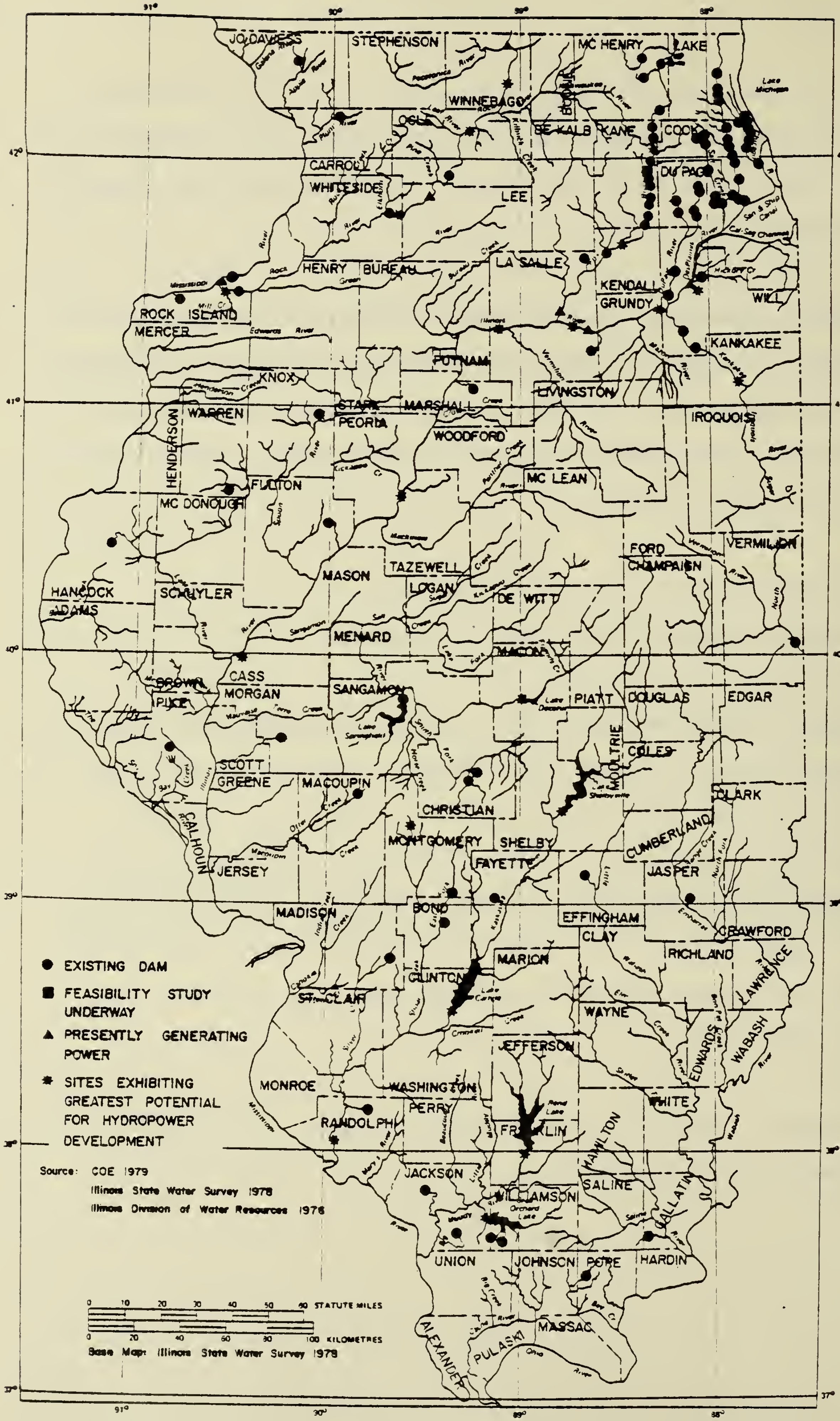
- The potential reduction of net power head because of rising tailwater conditions during high flows was not computed.

- The analysis technique of maximum net benefits, using incomplete project cost, resulted in a low plant factor operation. This type of operation could require more reservoir storage than is available for regulating power flows or could cause fluctuations in the surface elevation of the reservoir or downstream flow that would not be acceptable.

- Computations ignored diversion of water for other uses, as well as losses due to evaporation.

- Turbines were assumed to be 100% efficient, and head losses through penstocks were not estimated.

Figure 1. Existing dam sites in Illinois with potential for small-scale hydroelectric development.



- During periods of high flow, it was calculated that streamflow would pass through the turbines at the design discharge rate when in fact, during excessively high flows, the plant may be shut down because of high tail-water and reduced head.

- Summary tables include estimates of the potential capacity and energy at each site in the inventory. In some cases, individual projects may be site alternatives to others in the same general location, when only one can be considered for hydropower development.

- Detailed consideration of the social, economic, institutional and environmentally constraints associated with hydropower development were not specifically included in the analysis.

The combined generating capacity for the 57 sites for which head and flow data are available is estimated to be approximately 176 MW. These sites range in head from 8 feet to 98 feet, in flow from 2 cfs to 49,137 cfs, and in capacity from 50 KW to 32.24 MW. The mean generating capacity for the 57 sites is 3.19 MW. Twenty-five sites have a potential capacity over 350 KW while 21 sites have a potential capacity of less than 100 KW.

Flow data are a primary factor in determining the amount of power that can be generated at a site. Only average annual flow data are available in the COE's inventory. While preliminary estimates of a site's capacity can be made with these data, they are inadequate for making detailed assessments of a site's capacity. Flow duration curves constructed from daily flow data are needed to estimate more accurately total power capacity.

Detailed flow data also are necessary to determine the type of power that can be generated at a site. The value of power differs according to the type of power. Peak load power, the most valuable type of power, is power to supply a utility's peak demand for electricity. Firm, or dependable, power is power that can be relied upon to carry system load, to provide dependable reserve capacity, and to meet firm power obligations under the most extreme (high and low) flow conditions of record. Non-firm power is power that cannot be relied upon to carry system load, to provide dependable reserve capacity, or to meet firm power obligations. Dependable power is more valuable than non-firm power.

Thirty of the sites have average annual flows below 100 cfs. These sites would be capable of generating only non-firm energy, and probably would not generate power during low flow periods. Detailed analyses are needed to confirm this tentative conclusion.

Storage pools, if large enough, can sometimes be used to generate peak load power. Storage pools apparently exist at only 35 of the sites. The pools range from 1,000 acre-feet to 608,000 acre-feet. It appears that most sites, if developed, would have to be operated as run-of-the-river facilities with little potential for peak load generation, because most sites do not have storage pools. For those sites with pools, studies would have to be made to determine the potential for peak load generation.

Ownership data are available for only 49 of the sites. The Federal government owns 13 of the sites, including most of the major sites. The State owns 11 sites. Ownership data are not available for most of the smaller sites, but these are presumed to be owned primarily by local governments or by private interests.

Six hydroelectric plants currently are operating in Illinois. These plants have a combined capacity of 33 MW. Upgrading these six existing plants may be a viable way to increase hydroelectric power generation capacity in Illinois. The Preliminary Inventory indicates that approximately 100 MW of additional generating capacity could be obtained by upgrading these plants. This esitmate may be inflated. It represents a 300% increase in generating capacity for the six sites, and is approximately 57% of the total capacity estimated to be available at the 57 sites for which flow and head data are available. Because data concerning the methods used by the COE to calculate additional capacity at these sites are not yet available, the COE' estimate has not been confirmed.

The USCOE North Central Division released a draft report for the Main Reliability Council in September 1980 that refined the Preliminary Inventory. It identifies 17 sites in Illinois at which development appears economically feasible. This includes two sites on the Mississippi River. The total capacity of these sites is estimated to be between 176 mw and 249 mw, depending

on the method used for the computations.[4] The capacity of the Alton Lake site (Lock and Dam 26) on the Mississippi River is estimated to be 119 mw. The total capacity for the other 16 sites therefore is between 57 mw and 130 mw. Excluding the Alton Lake site, this represents a two- to four-fold increase in the current total State hydroelectric generating capacity. Considering that a megawatt of capacity can provide the electrical needs of between 1,000 and 2,000 people, the development of these sites potentially could provide the electrical needs of between 57,000 and 260,000 persons, depending on the estimate of capacity and the variables affecting use.

The same COE report concluded, "there is large potential for underground hydroelectric pumped storage owing to a large nuclear and coal generating base and the indicated availability of suitable sites." The study estimates that underground pumped storage could represent as much as 7% of the total generating capability of the Commonwealth Edison subregion in the year 2000. (Table 3) The Commonwealth Edison subregion comprises Bureau of Economic Analysis areas 77, 79 and 82.

[4] U.S. Corps of Engineers, North Central Divison. 1980. Main reliability council national hydroelectric power study. Draft. Department of the Army, Chicago, IL, variously paged, 120 pp, plus appendices.

Table 3[a]

Commonwealth Edison Subregion Generation Mix
(Percent of Total Capability)

Generation Type	1985 %	1990 %	1995 %	2000 %
Base				
Nuclear	47-39	43-46	38-40	36-40
Coal	15-17	18-20	22-25	23-26
Intermediate				
Coal	14-16	18-20	21-23	22-25
Oil	7-8	5-7	2-4	0-2
Other	0	0-1	0-1	1-2
Peaking				
Coal[b]	---	---	---	---
Oil	12-13	10-12	8-10	5-8
Pumped Storage	0	0	0-4	3-7
Other	0	0-1	0-1	1-2
Total Capability (GW)	24.2	28.4	35.1	43.4

[a] Source: Mid-America Interpool Network Reliability Council Hydropower Study.

[b] All coal fired plants are classified as either base or intermediate, although some intermediate cycling coal-fired plants will be capable of operating near the top of the load curve.

In February 1980, IINR commissioned WAPORA, Inc. to review the USCOE's Prelininary Inventory to identify the sites in Illinois with the greatest potential for development. This study, completed in the May 1980, also documented current reconnaissance and feasibility studies, license and permit applications, and construction activities at specific sites.

Twenty-one sites with a total potential generating capacity of approximately 117 mw were presented to an IINR-organized State review committee. (Table 4) Sites on the Mississippi River were not included because only sites completely within Illinois were considered. Excluding the Alton Lake site on the Mississippi River, this estimate of capacity is within the range of updated estimates more recently prepared by the USCOE North Central Division.

The State review committee selected five sites for additional study. These sites were selected on the basis of potential capacity, geographic location within the State, ownership, and whether there are competing uses for the water at the site. In addition, no sites already under study were selected. This single factor eliminated 10 of the 21 sites, including all but one with capacities estimated to be greater than 5 mw.

The reconnaissance-level studies commissioned by IINR for the five sites did not indicate conclusively that development at each site is economically feasible.[5] Favorable benefit/cost ratios for each site were estimated to be obtainable only when it was assumed that development at each site would be undertaken by a public entity using low-interest capital. It thus is difficult to ascertain the actual economic potential for increasing hydroelectric capacity in Illinois.

[5] WAPORA, Inc. 1980. Phase II report, preliminary investigation of small-scale hydropower potential at five sites in Illinois. Chicago, IL, 113 pp, plus appendices.

Table 4. Sites in Illinois exhibiting the greatest relative potential for development of small-scale hydroelectric power.

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Capacity (MW)
LaSalle	Illinois	Starved Rock Dam[a]	COE	14,420	15	0	15.76
Brown	Illinois	LaGrange Dam	COE	20,860	8	0	12.16
Franklin	Big Muddy	Rend Lake Dam	COE	4,034	40	608	11.76
LaSalle	Illinois	Marseilles[a,c,i]	COE	10,760	13	0	10.20
Will	Des Plaines	Brandon Rd. Pool[a,c,g]	COE	4,000[g]	34[g]	0	9.91[g]
Clinton	Kaskaskia	Carlyle Dam[a,b,c,e,f]	COE	3,500[h]	34[h]	0	8.75[h]
Peoria	Illinois	Peoria Dam	COE	13,300	9	0	8.75
Grundy	Illinois	Dresden Island[a]	COE	5,560	19	0	7.70
Shelby	Kaskaskia	Lake Shelbyville	COE	813	98	0	5.80
Ogle	Rock	Oregon[i]	IL Dept. of Conservation	4,200	9	0	3.00
Rock Island	Rock	Sears Dam[b,c,i]	IL Div. of Water Resources	6,524	11	0	5.23
Randolph	Kaskaskia	Navigation Pool[c,e]	COE	4,145	15	25	4.53
Kankakee	Kankakee	Kankakee,i	IL Dept. of Conservation	3,343	8	0	2.25
Whiteside	Rock	Upper Sterling/[i] Sinissippi Bayou	IL Div. of Water Resources	5,088	10	0	3.70
Macon	Sangamon	Lake Decatur	City of Decatur	663	24	22	1.16
Winnebago	Rock	Fordam[d,i]	Com. Edison Co.	1,559	9	0	1.02
Williamson	Crab Orchard Creek	Crab Orchard Lake	US Fish and Wildlife	266	38	166	0.74
Montgomery	West Fork Shoal Creek	Lake Lou Yeager	US. Soil Conservation Service	207	45	21	0.68
Kendall	Fox	Yorkville Dam	IL Division of Water Resources	2,100[j]	9	0	1.40
Kane	Fox	Elgin Kimball Street Dam[d,i]	Private	933	9.5	0	0.60

[a]Denotes sites for which a hydroelectric feasibility study is authorized, underway, or completed.

[b]Denotes sites for which a FERC Preliminary Permit has been granted.

[c]Denotes REI sites at which a COE Reconnaissance Study is warranted.

[d]Denotes REI sites at which a COE Reconnaissance Study is not warranted.

[e]Denotes REI sites at which a COE Reconnaissance Study has been completed.

[f]Denotes sites at which construction of a hydroelectric plant is scheduled.

[g]Data obtained from the USCOE Preliminary Feasibility Study for Hydropower at Brandon Lock and Dam.

[h]By telephone, Mr. Randy Thomas, Barnes, Henry, Meisenheimer and Gende, Inc., to Mr. Greg Lindsey, WAPORA, 2 May 1980.

[i]Denotes sites that previously generated electricity.

[j]Taken at a USGS sampling site near Montgomery IL, north of Yorkville.

Fifteen of the 21 sites originally identified by WAPORA now have been studied. The studies for the sties with larger capacities have indicated that development is economically feasible. The studies conducted by WAPORA for IINR were for relatively small sites, and the economic potential was found to be marginal at best. The cost per kilowatt to develop these sites ranged from about $1,600/kw to about $2,700/kw and break-even revenue requirements ranged between 38 mills/kwh and 83 mills/kwh.[6] Cost generally increased as capacity decreased and according to the level of expenditures for civil works. Thus, it does not appear that development would be economically feasible at all of the sites identified by the USCOE or by the IINR as the sites with the greatest potential. Therefore, at the present time, the actual potential for economically increasing the hydroelectric generating capacity in Illinois is somewhat less than the estimated 117 mw, and probably closer to the USCOE North Central Division's estimate of 57 mw.

[6] Ibid.

HYDROPOWER TECHNOLOGY

Hydroelectric power generation is a process in which the potential energy of water is converted into mechanical energy as the water is channeled through a hydraulic turbine, and then into electricity by a generator connected to the turbine. The amount of power that can be produced at a particular site is a function of the flow at the site, the head at the site, and the efficiency of the generation process.

Flow is the quantity of water passing a specific point within a given period of time. Head is the difference between water elevation at entry into the hydroplant and water elevation at the point of discharge from the plant. The efficiency of the process depends on the configuration of the hydroplant and the type and efficiency of the system components such as the turbine(s) and whether penstocks are required. For example, if penstocks are required, friction losses reduce the available head and less power can be generated.

A schematic for a typical small-scale hydroplant is presented in Figure 2. Figure 2 includes three separate drawings. The "Location Plan" illustrates how a hydroplant is located on a river. The "Cross Section" presents the mechanical and electrical features of a facility, and the "Plan" shows how turbines would be placed in a facility. This drawing was developed as part of a specific preliminary investigation of hydropower potential at the Elgin Dam on the Fox River in Elgin, Illinois[7]; but is representative of most small-scale hydropower arrangements.

[7] Ibid.

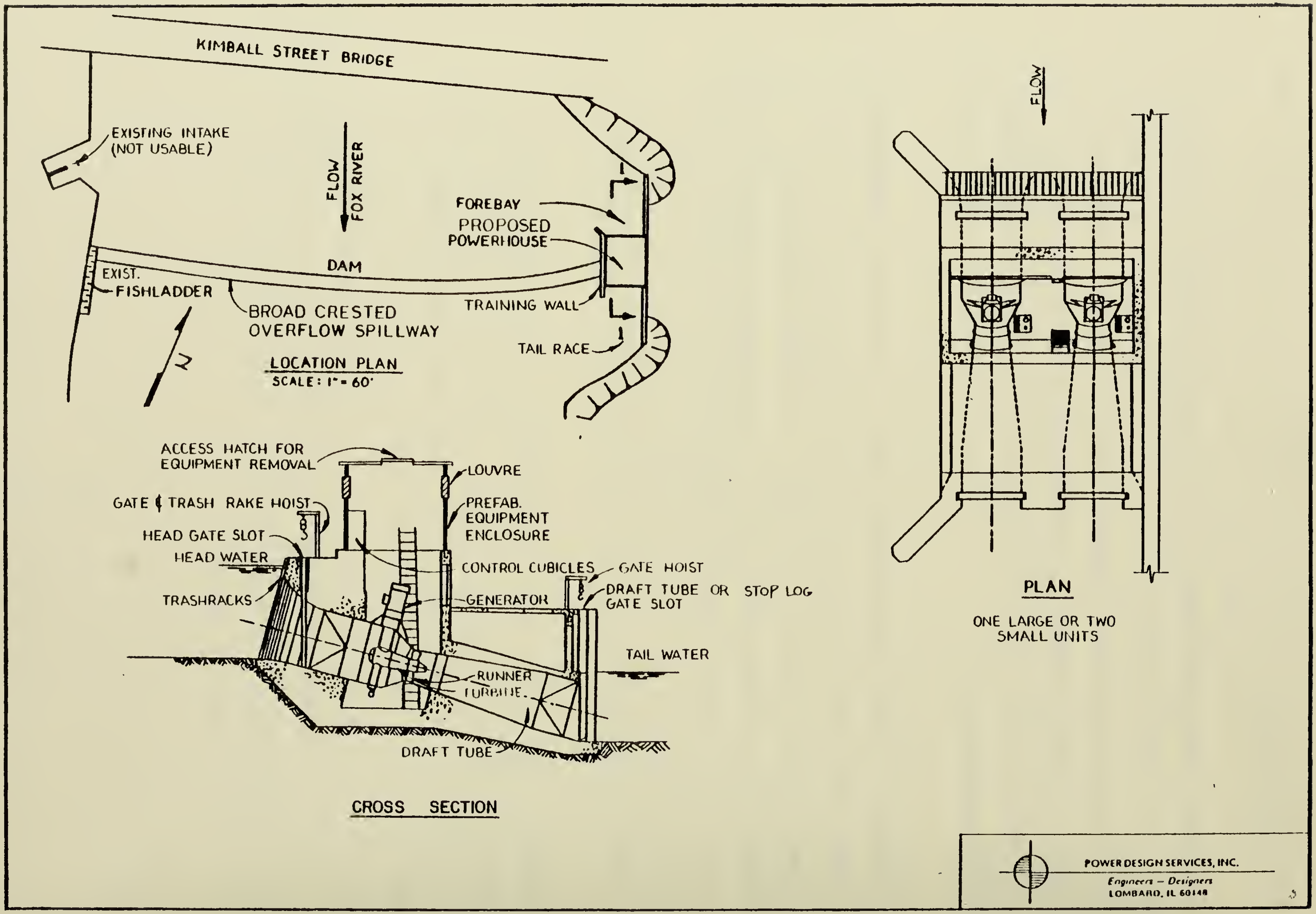


Figure 2. Typical configuration for a small-scale hydroplant (Based on conceptual design for hydropower development at Elgin IL; PDS 1980).

Almost all hydropower configurations involve the use of a dam to direct water through a powerhouse that contains mechanical and electrical generating equipment. The dam increases the depth of the water (and therefore the head) and permits regulation of flow.

The Location Plan in Figure 2 illustrates the site layout including the river, dam and powerhouse. Water is diverted through the forebay into the powerhouse and is discharged through the tailrace back into the river.

The Cross Section illustrates the main mechanical and electrical features of the facility. The headwaters enter the turbine unit through the trashracks, which prevent debris from entering the unit. The runner is the turbine blade, which is turned by the force of water passing over it. The turbine is connected to the generator, where the mechanical energy is converted to electricity. The water then is discharged through the draft tube into the tailwaters. The head gate slot and draft tube gate slot are for gates used to seal the plant when it is necessary to discontinue operation because of low flow or for maintenance or repairs. The hoists are the mechanisms for raising and lowering the head gates, trash rakes and draft tube gates. The control cubicles house the electrical equipment. The equipment enclosure (powerhouse) is a structure that contains the generating equipment. The louvre provides ventilation, and the access hatch permits the removal of equipment when replacement is required.

The Plan in Figure 2 is an overview section that illustrates how turbines could be installed in the facility. The number of units in the facility is dependent on the site capacity.

Although penstocks and/or power canals are not depicted in Figure 2, they are required for the development of some sites. Both penstocks and power canals provide a means of channeling water to the turbine. A penstock is a conduit or pipe, while a power canal is a channel or raceway. Hydropower facilities that incorporate penstocks sometimes involve surge tanks that prevent undesirable water pressure changes that could damage the pipeline and turbines.

The operation of some hydroplants may involve the manipulation of the reservoir behind the dam to maximize or to time power production. Hydropower operations that do not involve regulation of a reservoir behind the dam are termed run-of-the-river operations and simply utilize the normal flow of the river to produce power.

An additional method of utilizing hydropower is termed pumped storage which is an arrangement whereby electric power is generated during peak load periods by using water previously pumped into a storage reservoir during off-peak periods. Off-peak baseload power is used to power pumping units (reversible pump/turbines) to move water "upstream" for temporary storage. When peaking power is required, the water is allowed to flow through the turbines and generate power.

Technological advancements in equipment manufacture and standardization, and in methods of gaining optimum output from a site are continually occurring. However, the major constraints to the development of conventional hydropower in Illinois beyond 57 to 130 MW have less to do with technological advancements than with topography, environmental considerations with regard to construction of new impoundments, and competing water uses.

Technological advancements will lower the cost of utilizing the resource. Two encouraging advancements are: 1) turbine standardization and 2) the development of equipment capable of economically utilizing ultra-low head (less than 10 feet) sites.

Additionally, the cost of utilizing hydropower resources will become increasingly attractive as the cost of utilization of other resourcs for the purpose of electric power generation increases at a rate relatively faster than the costs of hydropower. As the cost of fossil and nuclear fuels increases, and the cost of environmental controls for utilizing these resources increases, the cost of utilizing hydropower will increase less rapidly due to the fact that hydropower is relatively environmentally benign and uses as a "fuel" the water resources of the region which are continually renewed by the hydrologic cycle.

A significant technological development of the hydro turbine industry has been the standardization of turbines. In order to provide a lower cost, small-scale hydroelectric unit, manufacturers are developing standardized conventional turbine units covering a wide range of flows and heads,

applicable to heads up to 50 feet. They are not simply scaled down large units, but rather new design and manufacturing concepts have been incorporated to further reduce costs. The major benefits derived from standardization as opposed to the past practice of custom designing each turbine-generator unit to meet the hydraulic conditions at an individual site include the following:

1) facilitate previously marginal sites
2) spread design costs over multiple units
3) utilize available components
4) simplify and therefore reduce cost of feasibility studies
5) realize economies of scale
6) realize faster delivery of power generation equipment

A second promising development centers around the design of a low-cost, ultra low-head hydropower package based on marine thrusters.

A recently completed research and development study, co-funded by the U.S. Department of Energy and Energy Research and Applications, Inc., has addressed cost reduction for ultra-low head hydropower development. This effort has yielded a design for an innovative, low cost, ultra-low head hydropower package, based on modular assembly of "off-the-shelf" components and materials. The approach avoids custom design and fabrication for individual sites, which drives up costs.

The prime mover, or blade, section of the package hydroturbine is a standard marine thruster. (Marine thrusters are essentially pump-like propulsion units for maneuvering ships in tight places; they look much like propeller turbines.) The thrusters can be adapted, through design and fabrication, into hydroturbines configured to power induction or synchronous generators prematched to the turbine size. Further testing of the concept remains. However, the outlook for the technology is encouraging.

CONCLUSION

The addition of 57 mw of hydroelectric generating capacity (a reasonable estimate of currently feasible addition), would nearly double Illinois' present total hydroelectric capacity. However, in terms of the total electric generating capacity of the State, hydropower's contribution still would be relatively small. This does not mean that hydropower is not an important source of power. As costs for conventional energy sources and social and environmental concern about power plant siting increase, the development of new, conventional, centralized power sources will become increasingly constrained. Therefore, it will be important to develop all potential sources of power, especially those with minimal environmental impact. Because the increased demand for energy in Illinois will not be met by a single source of power, hydropower, despite its limited potential, will be an important alternative source of renewable energy for supplying the State's energy needs.

REFERENCES

Federal Power Commission. 1953. Hydroelectric power resources of the United States, developed and undeveloped. Federal Power Commission, Bureau of Power, Washington, DC.

US Corps of Engineers. 1979. Preliminary inventory of hydropower resources, national hydroelectric power resources study volume 4, Lake Central region. US Dept. of the Army, Institute for Water Resources and Hydrologic Engineering Center, Ft. Belvoir VA, variously paged.

US Corps of Engineers, North Central Division. 1980. Main reliability council national hydroelectric power study. Draft. Department of the Army, Chicago IL, variously paged, 120 pp, plus appendices.

Shanks, Kenneth J. 1979. Inventory of power plants in the United States--April 1979. US Department of Energy, Energy Information Administration, Washington DC, variously paged.

WAPORA, Inc. 1980. Phase I report, inventory of potential small-scale hydropower sites in Illinois and selection of projects exhibiting potential for development. Chicago IL, 29 pp. plus appendices.

WAPORA, Inc. 1980. Phase II report, preliminary investigation of small-scale hydropower potential at five sites in Illinois. Chicago IL. 113 pp. plus appendices.

APPENDIX A

INVENTORY OF EXISTING DAMS IN ILLINOIS

Inventory of existing dams in Illinois.

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Estimated Capacity (MW)	Source*
Bond	Kingsbury Branch	Greenville New City Lake		24	35	12	0.06	COE 1979
Brown	Illinois	LaGrange Dam	COE	20,864	8	0	12.17	COE 1979
Carrol	East Fork	IL No Name 872	Private	6	47	22	0.02	COE 1979
Christian	Clear Creek	IL No Name 650		44	42	35	0.13	COE 1979
Christian	S. Fork Sangamon-Offstream	IL No Name 656		74	20	0	0.11	COE 1979
Clinton	Kaskaskia	Carlyle Dam[a,b,c,e,f]	COE	3,500[h]	34[h]	0	8.75[h]	COE 1979
Cook	Des Plaines	Dam 1						ISWS 1978
Cook	Des Plaines	Dam 2						ISWS 1978
Cook	Des Plaines	Dempster St. Dam						ISWS 1978
Cook	Des Plaines	Touhy Ave. Dam						ISWS 1978
Cook	Des Plaines	Devon Ave. Dam						ISWS 1978
Cook	Des Plaines	Armitage Ave. Dam						ISWS 1978
Cook	Des Plaines	Hoffman Dam						ISWS 1978
Cook	Des Plaines	Fairbanks Rd. Dam						ISWS 1978
Cook	West Branch Salt Creek	Busse Woods (North) Dam						ISWS 1978
Cook	West Branch Salt Creek	Busse Woods (Middle) Dam						ISWS 1978
Cook	West Branch Salt Creek	Busse Woods (South) Dam						ISWS 1978
Cook	Salt Creek	Salt Creek Diversion Weir						ISWS 1978
Cook	Skokie	Voltz Rd. Dam						ISWS 1978
Cook	Skokie	Tower Rd. Dam						ISWS 1978
Cook	Skokie	Pine St. Dam						ISWS 1978
Cook	Skokie	Willow Rd. Dam						ISWS 1978
Cook	Skokie	Winnetka Rd. Dam						ISWS 1978
Cook	N. Branch-Chicago	Glen View C.C. Dam	Glenview C.C.					ISWS 1978
Cook	N. Branch-Chicago	West River Pk. Dam	Chicago Pk. Dist.					ISWS 1978
DuPage	Salt Creek	Elmhurst County Club Dam	Elmhurst C.C.					ISWS 1978
DuPage	Salt Creek	Oak Brook Dam						ISWS 1978
DuPage	Salt Creek	Oak Brook Gates Dam						ISWS 1978

*COE = Corps of Engineers; ISWS = Illinois State Water Survey; IDWR = Illinois Division of Water Resources.

Inventory (continued).

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Estimated Capacity (MW)	Source*
DuPage	Salt Creek	Fullersburg Park Grist Mill Dam						ISWS 1978
DuPage	E. Branch-DuPage	Churchill Woods Dam						ISWS 1978
DuPage	E. Branch-DuPage	Churchill Woods Weir						ISWS 1978
DuPage	E. Branch-DuPage	Morton Arbor. Dam	Morton Arboretum					ISWS 1978
DuPage	W. Branch-DuPage	Warrenville Dam						ISWS 1978
DuPage	W. Branch-DuPage	Warrenville Weir						ISWS 1978
DuPage	W. Branch-DuPage	McDowell Grove Dam						ISWS 1978
Effingham	Blue Point Creek	Lake Sara		8	43	15	0.03	COE 1979
Fayette	Bear Creek	Vandalia City Lake		17	25	9	0.03	COE 1979
Franklin	Big Muddy	Rend Lake Dam	COE	4,034	40	608	11.76	COE 1979
Fulton	W. Branch Copperas	IL No Name 179		9	39	4	0.03	COE 1979
Gallatin	Trib. - Ohio	Eagle Slurry Pond		2	51	0	0.01	COE 1979
Grundy	Illinois	Dresden Island[a]	COE	5,560	19	0	7.70	COE 1979
Hancock	Rocky Run Creek	Rocky Run	Hunt-Lima Lake Drainage District	4	45	4	0.01	COE 1979
Jackson	Kinkaid Creek	Kinkaid Lake	IL Div. of Water Resources	57	80	79	0.33	COE 1979
Jackson	Cedar Creek	Cedar Lake		40	73	80	0.21	COE 1979
Jasper	Heather Creek	Newton Power Station Lake		32	38	44	0.09	COE 1979
Jo Daviess	Hells Branch	IL No Name 94	Private	9	60	11	0.04	COE 1979
Kane	Fox	Carpentersville Dam[d,i,]	Tinicum Inc., Elgin Natl. Bank Tr. 625 First Natl. of Elgin TR. 1616	875	9	0.8	0.57	IDWR 1976
Kane	Fox	Elgin Kimball St. Dam[d,i,]	Wm. C. Kimball & James T. Gifford	933	9.5	0	0.60	IDWR 1976
Kane	Fox	S. Elgin Dam[d,i,]	IL Division of Water Resources					IDWR 1976
Kane	Fox	St. Charles Dam[a,d,i,] Hotel Baker	Lutheran Social Services of Illinois				0.14[j]	IDWR 1976
Kane	Fox	Geneva Dam[d,i,]	IL Division of Water Resources					IDWR 1976

*COE = Corps of Engineers; ISWS = Illinois State Water Survey; IDWR = Illinois Division of Water Resources.

Inventory (continued).

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Estimated Capacity (MW)	Source*
Kane	Fox	Batavia Upper Dam[d,i],	James Lathem	1,099	9	0.4	0.72	IDWR 1976
Kane	Fox	Batavia Lower Dam[i],	Elijah S. Town	1,105	8	0.4	0.64	IDWR 1976
Kane	Fox	N. Aurora Dam[d,i]	IL Division of Water Resources			0.9		IDWR 1976
Kane	Fox	Aurora E. & W. Dams[i],	IL Division of Water Resources	1,164	9	0.3	0.76	IDWR 1976
Kane	Fox	Aurora North Ave. Dam'	Theodore Lake & Fox Valley P.D.	1,142	9	0.4	0.75	IDWR 1976
Kane	Fox	Montgomery Dam	IL Division of Water Resources	1,197	8	0.3	0.70	IDWR 1976
Kankakee	Kankakee	Kankakee[c,i]	IL Dept. of Conservation	3,343	8	0	2.25	COE 1979
Kendall	Fox	Yorkville Dam	IL Division of Water Resources	2,100[m]	9	0	1.40	IDWR 1976
Kendall	Fox	Millhurst Dam	IL Division of Water Resources					IDWR 1976
Knox	Sugar Creek	IL No Name 405		11	49	15	0.04	COE 1979
Lake	Des Plaines	Libertyville Rock						ISWS 1978
Lake	Des Plaines	Dam 1C						ISWS 1978
Lake	Des Plaines	Dam 1B						ISWS 1978
Lake	Des Plaines	Dam 1A						ISWS 1978
Lake	W. Fork N. Branch Chicago River	Riverwoods Dam						ISWS 1978
LaSalle	Rocky Run	Tiskila Stru. 2		9	44	1	0.03	COE 1979
LaSalle	Illinois	Marseilles[l]	COE – IL Power Co.	5,065	14	0	2.3[k]	COE 1979
LaSalle	Illinois	Marseilles[a,c,i]	COE	10,760	13	0	10.20	COE 1979
LaSalle	Illinois	Starved Rock Dam[a]	COE	14,420	15	0	15.77	COE 1979
LaSalle	Fox	Dayton Dam[l]	No. Counties Hydro-Elec. Co.	1,611	28	1	4.0[k]	COE 1979
LaSalle	Somonauk Creek	IL No Name 437		39	28	4	0.08	COE 1979
Lee	Rock	Dixon[l]	Com. Edison Co.	5,079	9	6	4.0[k]	COE 1979
Macon	Sangamon	Lake Decatur	City of Decatur	663	24	22	1.16	COE 1979
Macoupin	W. Fork – Otter Creek	Otter Lake		64	51	15	0.24	COE 1979

*COE = Corps of Engineers; ISWS = Illinois State Water Survey; IDWR = Illinois Division of Water Resources.

Inventory (continued).

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Estimated Capacity (MW)	Source*
Madison	East Fork - Silver Creek	Silver Lake		33	30	8	0.07	COE 1979
Marshall	Shaw Creek	IL No Name 96		10	68	7	0.05	COE 1979
McHenry	Nippersink Creek	IL No Name 562		57	16	7	0.07	COE 1979
McHenry	Trib. - Fox	IL No Name 568		7	39	1	0.02	COE 1979
McHenry	Fox	McHenry Dam	IL Division of Water Resources					IDWR 1976
McHenry	Fox	Algonquin Dam	IL Division of Water Resources					IDWR 1976
Montgomery	Trib. - McDavid Branch	Central Illinois		61	50	28	0.22	COE 1979
Montogomery	W. Fork - Shoal	Lake Lou Yeager	Soil Cons. Service	207	45	21	0.68	COE 1979
Morgan	Sandy Creek	Lake Jacksonville		12	42	7	0.04	COE 1979
Ogle	Rock	Oregon[1]	IL Dept. of Conservation	4,200	9	0	3.00	COE 1979
Ogle	Rock	Grand Detour		5,343	24	0	9.35	COE 1979
Peoria	Illinois	Peoria Dam	COE	13,300	9	0	8.73	COE 1979
Pike	Blue Creek	IL No Name 717	City of Pittsfield	9	25	7	0.02	COE 1979
Pope	Bay Creek	Bay Ck. Str. 5		17	37	6	0.05	COE 1979
Randolph	Kaskaskia	Kaskaskia River[c,e] Navigation Pool	COE	4,145	15	25	4.53	COE 1979
Randolph	Trib. Kaskaskia	Baldwin Lake		61	32	26	0.14	COE 1979
Rock Island	Rock	Sears Dam[b,c,1]	IL Division of Water Resources	6,524	11	0	5.23	COE 1979
Rock Island	Rock	Steel Dam						
Rock Island	Big Branch	IL No Name 98[1]	Rock Island County Preserve Dist.	4	52	4	0.02	COE 1979
Rock Island	Mississippi	Arsenal Dam[d]						
Rock Island	Sylvan Slough	Moline Generating[1,c] Station Dam	Iowa - Illinois Gas & Elec.	49,137	9	2	3.6[k]	COE 1979
Sangamon	Sangamon	Lake Springfield						
Shelby	Kaskaskia	Lake Shelbyville Dam	COE	813	98	0	5.81	COE 1979
Vermilion	Vermilion	Lake Danville						
Warren	Little Swan Creek	IL No Name 448	Private	6	29	3	0.01	COE 1979

*COE = Corps of Engineers; ISWS = Illinois State Water Survey; IDWR = Illinois Division of Water Resources.

Inventory (concluded).

County	River	Project Name	Owner	Ave. Flow (cfs)	Net Power Head (Feet Usable)	Max. Storage (1000 Acre Feet)	Estimated Capacity (MW)	Source*
Whiteside	Rock	Upper Sterling[i] Sinissippi Bayou	IL Div. of Water Resources		10	0	3.71	COE 1979
Whiteside	Rock	Sterling Lower Dam[i]						IDWR 1976
Will	Des Plaines	Brandon Rd. Pool[a,c,g]	COE	4,000	34	0	9.90	COE 1979
Will	Chicago Sanitary and Shipping Canal	Lockport Pool[l]	Metropolitan Sanitary District of Greater Chicago	507	38	0	17.0[k]	COE 1979
Will	Kankakee	Wilmington Dam[d,i]	Wilmington Park District					IDWR 1976
Will	Kankakee	Custer Park						IDWR 1976
Will	DuPage	Hammel Woods Dam						ISWS 1978
Will	DuPage	Channahon						ISWS 1978
Will	Hickory Creek	Highland Park Dam	City of Joliet					ISWS 1978
Williamson	Crab Orchard Creek	Crab Orchard Lake	US Fish & Wildlife	266	38	166	0.74	COE 1979
Williamson	Little Grassy Creek	Little Grassy Lake		17	78	34	0.10	COE 1979
Williamson	Big Grassy Creek	Devil's Kitchen Lake		23	80	106	0.13	COE 1979
Winnebago	Rock	Rockton[l]	S. Beloit Water Gas & Elec. Co.	1,566	15	0	1.1[k]	COE 1979
Winnebago	Rock	Fordam (Rockford)[d,i]	Com. Edison Co.	1,559	9	0	1.02	COE 1979

*COE = Corps of Engineers; ISWS = Illinois State Water Survey; IDWR = Illinois Division of Water Resources.

[a]Denotes sites for which a hydroelectric feasibility study is authorized, underway, or completed.

[b]Denotes sites for which a FERC Preliminary Permit has been granted.

[c]Deontes REI sites at which a COE Reconnaissance Study is warranted.

[d]Denotes REI sites at which a COE Reconnaissance Study is not warranted.

[e]Denotes REI sites at which a COE Reconnaissance Study has been completed.

[f]Denotes sites at which construction of a hydroelectric plant is scheduled.

[g]Data obtained from the USCOE Preliminary Feasibility Study for Hydropower at Brandon Lock and Dam.

[h]By phone, Mr. Randy Thomas, Barnes, Henry, Meisenheimer and Gende, Inc., to Mr. Greg Lindsey, WAPORA, 2 May 1980.

[i]Denotes sites that previously generated electricity (FERC no date).

[j]From Mitchell Engineering Ltd (1979).

[k]From Shank (1979).

[l]Denotes sites which currently generate power.

[m]Taken at a USGS sampling station near Montgomery IL, north of Yorkville.